PHYSICS AND CHEMISTRY
OF
MINING AND MINE VENTILATION

A PRACTICAL HANDBOOK

FOR VOCATIONAL SCHOOLS, AND FOR THOSE QUALIFYING FOR MINE FOREMAN AND MINE INSPECTOR CERTIFICATES

BY

JOSEPH J. WALSH
Mine Inspector, Wilkes-Barre, Pa.

SECOND EDITION, REVISED AND ENLARGED

ILLUSTRATED

NEW YORK
D. VAN NOSTRAND COMPANY
25 PARK PLACE
1918

PREFACE TO SECOND EDITION

All the general features contained in the first edition which students and others interested in the physics and chemistry of mining and mine ventilation, commended, have been retained in this revised edition. The chapters dealing with gases and mine ventilation have undergone revision, and new material added.

The chapter treating of the sampling and analysis of mine gases is new, and has been written to supply a need which has arisen in teaching gas analysis and also to meet the growing demand for a more thorough knowledge of this branch of mining. In this chapter, mine gases are treated in a more practical way than is the custom in ordinary books on the subject. The properties of gases and the changes which affect their composition, together with the products of the combustion of gases, are clearly defined.

The author appreciates the cordial reception given the first edition of his book and trusts the revised edition will meet with favor and speedily find a larger field of usefulness.

J. J. W.

Wilkes-Barre, Pa.,
April 15, 1918.

PREFACE TO FIRST EDITION

In adding to the number of text-books on Mine Ventilation the author aims to provide new material and to dwell more fully on the fundamental theories and laws of ventilation, and to furnish, if possible, to the student a more suggestive method of study in a more graphic form.

While ventilation experts practically agree upon the essential theorems in ventilation, it is believed, however, that the subject may yet hold a new attractiveness and be more readily mastered if a few important principles, which are now generally misunderstood by the student, are magnified.

The method of determining the size of fan, etc., to ventilate a mine under given conditions, together with certain facts pertaining to the water gauge, and the chapter on Mine Fires are entirely new features.

The author wishes to express his gratitude to the Robinson Ventilating Co. of Pittsburgh, Pa.; The American Blower Company, and their manager, Thomas W. Fitch, Jr., Detroit, Mich.; The Jeffrey Manufacturing Co., Columbus, Ohio; The Colliery Engineer, Scranton, Pa.; M. B. King, Expert Assistant in Industrial Education, Harrisburg, Pa.; and The Taylor Instrument Co., Rochester, N. Y., for many illustrations, tables and other information used in this book.

J. J. W.

Wilkes-Barre, Pa.,
June 1, 1915.

CHAPTER VI

Gases

CHAPTER VII

Gases

CHAPTER VIII

Barometer

CHAPTER IX

Gases

CHAPTER X

Specific Heat

CHAPTER XI

Air Analysis

CHAPTER XII

Mine Ventilation

CHAPTER XIII

Mine Ventilation

CHAPTER XIV

Formulas

CHAPTER XV

Mine Fires

CHEMISTRY OF MINING AND MINE VENTILATION

CHAPTER I

PROPERTIES OF MATTER

1. Matter.—The term "matter" is one which has a very wide meaning. To say that "matter is that which occupies space," adds little if anything to our common understanding of the term. Matter includes all things which exist of which we can become aware by our sense of sight, touch, taste, smell and hearing. There are numerous different kinds of matter and they are usually indicated by the term SUBSTANCE. Thus air, coal, iron, wood, water, etc., are different kinds of matter, also different substances.

Matter may be classified under three distinct heads: namely, solids, liquids, and gases.

2. Properties of Matter.—Matter is possessed of certain peculiar qualities which serve to define it. These properties are either GENERAL or SPECIFIC.

General Properties are those found in all matter, such as EXTENSION, DIVISIBILITY, IMPENETRABILITY, POROSITY, INERTIA, INDESTRUCTIBILITY.

Specific properties are those found in certain kinds of matter only, such as DUCTILITY, HARDNESS, MALLEABILITY.

3. Extension.—All bodies have extension in three direc-

tions, and occupy space, commonly called length, breadth, and thickness. The absence of any one of these three dimensions is sufficient to prove that the thing under consideration is not matter. Hence, lines and surfaces are not bodies in the physical sense.

4. Impenetrability.—This property means that no two bodies, however small, can occupy the same space at the same time. When a stone is dropped into a tumbler full of water some of the water overflows. If the volume of the stone is one cubic inch, exactly one cubic inch of water is displaced. A nail driven into a block of wood pushes the substance of the wood together; the wood now occupies only part of the space it originally occupied.

5. Porosity.—All matter is porous, that is, the particles of matter of which a body is composed do not fill the entire volume occupied by it. The molecules of a body are spherical therefore there is space between them. Hence, a blotter will absorb ink, lime will absorb carbon dioxide, without change of volume. Glass, iron and other hard substances are known to be porous.

6. Compressibility.—The compressibility of a substance is evidence of its porosity. Gases are very compressible, solids to a much less degree, and liquids are almost incompressible. If the pressure upon a gas is doubled, temperature remaining the same, its volume is diminished one-half. While changing the pressure upon water in the same manner its volume diminishes only $\frac{1}{20000}$.

7. Indestructibility.—Matter can be made to assume different forms as the result of PHYSICAL and CHEMICAL CHANGES. Sometimes the change is only temporary, as in the freezing of water or in the melting of iron. Such changes are called PHYSICAL CHANGES. In this case the substance does not lose its identity, but may be restored by merely mechanical means to its original state when the

original temperature is resumed. But often the change is permanent, as in the burning of coal, the rusting of metals; in this case the original cannot be restored by mechanical means. Changes in which a substance thus loses its identity are called CHEMICAL CHANGES.

Matter may be changed by crushing, burning, cooking and mixing with other substances; but MATTER ITSELF CANNOT BE DESTROYED. The number of atoms in the universe is exactly the same now as it was hundreds of years ago.

8. Divisibility.—Divisibility is that property of matter which indicates that a body can be divided into smaller parts without changing the matter of which it is composed.

9. Inertia.—Inertia is the tendency possessed by a body to remain at rest or in motion. A body cannot put itself in motion or bring itself to rest. To do either, it must be acted upon by some force outside of itself.

Use is made of inertia, as in driving on the head of a hammer by striking the end of the handle. The violent jar to a water pipe on suddenly closing the faucet is due to the inertia of the stream.

10. Elasticity.—This property exhibited by matter indicates that if a body be distorted within its elastic limit it will resume its original form when the distorting force is removed.

Apply pressure to a rubber ball, stretch a rubber band, bend a piece of steel. In each case the original form is changed, but the body readily recovers from the strain on the removal of the stress, and will resume its original form if not distorted beyond its elastic limit.

All bodies, whether solids, liquids, or gases, when reduced in volume by addition of pressure, regain or partly regain their volume when this added pressure is removed. A piece of wood may be compressed to half its volume and

when released it expands, but does not nearly return to its original volume. It has been compressed beyond its ELASTIC LIMIT.

Liquids and gases have no ELASTIC LIMIT. No amount of compression can permanently change their volume; they always return to their original volume when the distorting pressure is removed.

HOOKE'S LAW.—*Whenever the forces that produce distortions in any body are within the elastic limit, the distortions produced are directly proportional to the forces that produce them.* That is, if a one-pound weight be suspended from a spring balance, and the stretch of the spring measured, after which a four-pound weight be suspended in the same manner, it will be found that the four-pound weight will stretch the spring four times that of the one-pound weight.

11. Cohesion.—When we try to break a piece of wood, we are conscious of a force tending to hold the parts together. Hence, COHESION gives to solids their stability of form. All bodies are made up of small particles called molecules, and COHESION is the natural attraction that these particles have for each other. It is measured by the force required to pull them apart.

The COHESION is not as strong in liquids as in solids. In fact, it is not sufficient to maintain the form, yet the molecules in a drop of water hanging from the roof of a mine have sufficient attraction for each other to support the weight of the drop, unless it becomes so large that the weight is greater than the COHESION.

In gases the molecules are so far apart that there is very little COHESION between them. On account of this gases cannot be moved by a pull, they must be moved by a push or pressure. Air cannot be pulled through the airways of a mine; it is moved by reason of pressure.

Likewise water must be moved by pressure; its force of COHESION is not sufficient to allow it to be pulled.

QUESTIONS

1. What different forms can water be made to assume by changing its temperature?

2. Why can the head of a hammer be driven on the handle better by striking the end of the handle against a stone than by striking the head against the stone?

3. How would you find the volume of a piece of coal by displacement?

4. Under how many heads is "matter" classified? What are they?

5. Can matter be destroyed?

6. What is Hooke's law of elasticity? Give an example of its application.

7. If the pressure upon a volume of gas is doubled, what change takes place in the volume of the gas, and to what extent?

8. If the pressure upon a volume of water is doubled, to what extent is the volume reduced?

9. What is meant by the term "inertia"?

10. If a hoisting rope on a shaft is stretched beyond its elastic limit will the rope recover from the strain after the stress is removed?

11. What do you understand by the term "COHESION"?

12. Why cannot air be pulled through a mine?

13. (*a*) If a stone, one-half cubic foot in volume, be dropped in a vessel filled with water, how much water is displaced? (*b*) If water weighs 62.5 lbs. per cubic foot, what weight of water does the stone lift? (*c*) How much less will this stone weigh under water?

CHAPTER II

MOTION, VELOCITY AND FORCE

12. Motion.—Motion is a change of place, and is the opposite of rest. Or, motion is the change in the relative position of a body with respect to some point or place.

When a body moves in a path which constantly changes in direction, it is said to move in a curve. Strictly speaking all bodies moving in space are constantly changing in direction. A ball dropped from a balloon moves toward the center of the earth, but as the earth itself is moving around the sun, the path of the ball must be in a curving direction. For this reason a stone dropped into a deep shaft will strike the side before it reaches the bottom; however, for all practical purposes the slight curvature referred to may be neglected.

13. Newton's First Law of Motion.—Every body continues in its state of rest, or uniform motion in a straight line, except in so far as it may be compelled by force to change that state. Newton states in this law that a state of uniform motion is just as natural as a state of rest. This is at first difficult to realize, because rest seems the natural state and motion the enforced one. But difficulty is at once dispelled as soon as one begins to inquire into the causes that hinder the movement of a body artificially set in motion.

A rifle ball soon stops because resistance of the air continually lessens its speed, and finally gravity draws it down upon the earth.

A baseball rolling upon a level field soon stops because,

in moving forward, it must repeatedly rise against the attraction of gravity in order to pass over minor obstacles such as pebbles and mounds. There is also much surface friction.

If it were possible to fire a rifle ball into space very remote from the attraction of the solar system, it would travel for ages, because no attraction or atmosphere would resist its progress.

14. Newton's Second Law of Motion.—The second law reads: " Change of motion is proportional to force applied and takes place in the direction of the straight line in which the force acts. Thus, if a cannon ball is shot horizontally along a level surface and another ball allowed to drop vertically from the mouth of the cannon, they will both strike the surface at the same instant. This shows that the force which gives the cannon ball its horizontal movement has no effect on the vertical force, which compels both balls to fall to the surface."

15. Newton's Third Law of Motion.—To every action there is always an equal and opposite reaction.

To illustrate, in Newton's own words: " If you press a stone with your finger the finger is also pressed by the stone. And if a horse draws a stone tied to a rope the horse will be equally drawn back toward the stone, for the stretched rope, in one and the same endeavor to relax or unstretch itself, draws the horse as much toward the stone as it draws the stone toward the horse." There must be, and always is, a pair of forces equal and opposite.

Horse and stone advance as a unit because the muscular power of the horse exerted upon the ground exceeds the resistance of the stone.

In springing from a boat we must exercise caution, because the force necessary to shove the body out of the boat reacts and tends to push the boat from the shore.

16. Velocity.—Velocity is the rate of motion. When a body moves over equal spaces in successive equal times its motion is uniform; if it travels unequal spaces in successive equal times its motion is variable. For example, an engine controlled by a governor runs, practically speaking, with a uniform velocity. On the other hand the motion of a stone falling down a shaft is variable, for its speed is increasing each second as it descends.

17. Force.—Force may be defined as that which tends to produce motion or to hinder the motion of a body.

When two forces act on a body along the same line and in the same direction the resultant force is simply their sum, and it acts in the same direction as the forces. The same is true when there are more than two forces acting in the same direction.

When two forces act on a body along the same line, but in opposite directions, their resultant equals their difference, and it acts in the direction of the greater force.

For example, if an engine pulls on a train of cars with a force of 3000 lbs. and another pushes at the back with a force of 4000 lbs., the resultant force applied to move the train is 7000 lbs. But if one pulls with a force of 1000 lbs. in one direction and the other with a force of 800 lbs. in the other direction, the resultant force tending to move the train forward is only 200 lbs. Therefore, the resultant of two forces acting in the same straight line, but in opposite directions, is the difference of the given forces and acts in the direction of the greater.

18. Parallelogram of Forces.—Forces may be represented by lines drawn to the same scale.

EXAMPLE.—Suppose the force E (Fig. 1), to be 3 lbs. and acting along the line AC toward C and at right angles to the force F, which is 2 lbs. and acting toward B.

Represent force E by line AC drawn to scale, say one

inch equals 2 lbs., in like manner draw AB representing force F. Complete the parallelogram by drawing the dotted lines CD and BD (parallel to AB and AC respectively).

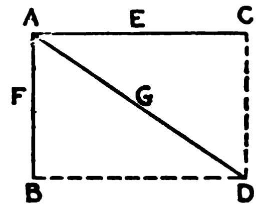


FIG. 1.

The magnitude and direction of the resultant of the two forces E and F will be equal to G and in the direction of line AD.

When the angle is a right angle, as in the present case, the diagonal AD is the hypotenuse of the right-angled triangle ACD; the force of G, being equal to the hypotenuse, is found as follows:

$$AD = \sqrt{3^2+2^2} = 3.606.$$

If the angle is not a right angle, the resultant can be found by measurement or by the principles of trigonometry.

EXAMPLE.—Suppose a sheave wheel and hoisting drum, as shown in Fig. 2, the rope passing from the drum around the sheave to the cage and making an angle of 30° with a vertical line. If the weight of the cage is 10 tons, (*a*) What force will then be on the shaft of the sheave wheel? (*b*) In what direction will the resultant force act?

Solution.—As the weight of the load is 10 tons the tension at any point along the rope is 10 tons, consequently there is a force of 10 tons acting from the sheave to the drum and also a force of 10 tons acting from the sheave to the load.

Produce the lines AB and BC to D, thus we have the point of application and direction of the forces. Using a scale of 1 inch = 5 tons, lay off from D a distance equal to 2 inches or 10 tons along lines DA and DC, then com-

plete the parallelogram by drawing line *FE* parallel to line *DC* and line *GE* parallel to line *DA*. Next draw line *DE*, which will be the direction in which the resultant force acts, and the length of *DE*, using the same scale as given above, will equal 19.5; therefore if the parts

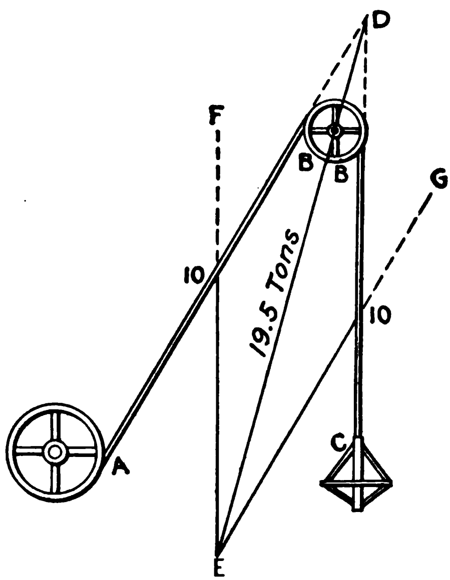


Fig. 2.

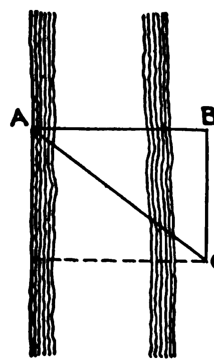


Fig. 3.

are not in motion the weight on the shaft of the sheave wheel is 19.5 tons.

Velocity can also be represented graphically. For example, if a man rows a boat across a stream with a uniform velocity of 4 miles per hour, and the stream flows with a uniform velocity of 3 miles per hour, the direction taken by the boat can be determined by the velocities. If the boat starts from *A*, Fig. 3, the path of the boat

may be found by laying off AB to represent the velocity of 4 miles per hour, and BC to represent the velocity of the stream, 3 miles per hour. Then AC will be the direction the boat will take. If the width of the stream is known line AC can be readily found.

QUESTIONS

1. Find the resultant of 30 lbs. north and 40 lbs. east. Represent forces and resultant graphically.

2. What is motion?

3. Why will a stone not fall down a deep shaft without striking the side of the shaft?

4. What is Newton's first law of motion?

5. If a man rows a boat across a river at the rate of 2 miles per hour and the river is flowing at the rate of 3 miles per hour, show graphically the direction of the boat.

6. If a cannon ball is shot horizontally along a level surface and another ball is allowed to drop from the mouth of the cannon at the same instant, neglecting the resistance offered by the air, which will strike the ground first?

7. A rope runs from a hoisting drum at an angle of 45° and passes over a sheave wheel which is directly over the center of the shaft; on the shaft end of the rope there is a cage weighing 8 tons; what is the force on the sheave wheel?

8. What is velocity?

9. If two forces act on a body along the same line and in the same direction, each force is equal to 100 pounds, what is the resultant force?

10. If two forces act on a body along the same line, but in opposite direction, one force is equal to 50 lbs., and the other 100 lbs., what is the resultant force and in what direction does it act?

CHAPTER III

GRAVITATION

19. The power called gravitation is the name given to the attractive force between different bodies. It is this power that prevents the earth, moon, and other heavenly bodies from swerving outside their paths in space. The force of the great law of gravitation is so evenly and constantly applied that, hundreds of years in advance, the places of planets in space and the exact hour, minute and second when eclipses will happen can be foretold. Regardless of this, what gravitation is, is not yet known. It is only known that it acts instantaneously over distances whether great or small, and no known substance interposed between two bodies has power to interrupt their gravitational tendency toward each other.

While the term GRAVITATION is applied to universal attraction existing between particles of matter, the more restricted term GRAVITY is applied to the attraction that exists between the earth and bodies upon or near its surface.

20. Newton's Law of Gravitation.—The law may be stated as follows: First, *that every particle of matter in the universe attracts every other particle directly as its mass or quantity of matter.* Second, *that the amount of this attraction increases in proportion as the square of the distance between the bodies decreases.*

21. Weight.—The weight of a body is the measure of the attraction that exists between the earth and that body.

Bodies weigh most at the surface of the earth. Below the

surface the weight decreases as the distance to the center decreases.

Above the surface the weight decreases as the square of the distance increases.

According to the above rule a body that weighs 100 lbs. at the surface of the earth will weigh nothing at the center, the body being attracted equally in all directions.

EXAMPLE.—If the radius of the earth is 4000 miles and a body on the surface weighs 200 lbs., what will it weigh 1000 miles below the surface?

Solution.—At 3000 miles from the center it will weigh 150 lbs. $4000-1000=3000$ and $4000 : 3000 :: 200 : 150$.

EXAMPLE.—If the same body was carried 1000 miles above the surface or 5000 miles from the center of the earth, it will weigh 128 lbs.

$$5000^2 : 4000^2 :: 200 : 128.$$

Therefore it can be seen that the weight of a body at any place is the attraction between it and the earth at that place. If two bodies have the same weight at a given place they must also have the same mass.

THE DIRECTION OF THE EARTH'S ATTRACTION.—When a plumb line is suspended from a certain point, the line is said to be vertical. Vertical lines suspended at different points on the earth's surface, if continued, would meet approximately at the earth's center, hence they are never strictly parallel, though practically so, provided they are near to each other.

22. Laws of Falling Bodies.—A body that is moving under the influence of gravity alone is a FREELY FALLING BODY. This condition can be obtained only in a vacuum, as the air constantly offers a resistance to the passage of any body through it.

If an iron ball and a piece of paper are dropped from the same height, the ball will strike the ground first. This is not because the ball is heavier, but because the resistance of the air has a greater retarding effect upon the paper. If the same ball and paper were placed in a glass tube from which all the air has been extracted, and allowed to fall as before, they would both fall with the same velocity and reach the bottom at the same instant.

Some bodies do not fall, but ascend. For example, a balloon in the air or a cork under water. This is not because the earth does not attract them, but because an equal bulk of the air or water immediately above the body contains a greater mass of matter and is therefore more strongly attracted by the earth than the body itself. The balloon and the cork are, by reason of the greater mass of air and water above them, consequently exchanging places, the greater mass sinking and forcing the smaller mass upward.

23. Effect of a Constant Force.—Whenever a body is falling freely under the influence of gravity only, regardless of its size, it will fall in the first second 16.08 ft., and its velocity at the end of the first second will be 32.16 ft. per second. This latter number is always denoted by g, and is the constant accelerating force exerted on all freely falling bodies. It should be understood that g varies at different points on the earth's surface, it being a little greater at the poles than at the equator. Careful experimenting has determined that at New York the acceleration of a freely falling body is, as stated, 32.16 ft.

The distance through which a freely falling body will move in a given time is equal to 16.08 multiplied by the square of the time in seconds.

EXAMPLE.—The distance a body will fall in 2 seconds equals 16.08 times 2^2 or 16.08 times 4 or 64.32 ft. In

3 seconds it will fall 16.08 times 3^2 or 16.08 times 9, or 144.72 ft.

24. Formulas for Falling Bodies.—The relations expressed by these formulas are usually known as the laws of falling bodies. They apply strictly to those bodies which fall without being hindered by the air or anything else.

Let t = number of seconds a body falls;
v = velocity at the end of the time;
h = distance that a body falls;
g = force of gravity, or accelerating force due to the attraction of the earth ($g = 32.16$).

EXAMPLE.—If it requires 10 seconds for a stone to fall down a shaft, what is its velocity at the end of the 10th second, assuming that the air offers no resistance?

Solution.—$v = gt$ or $32.16 \times 10 = 321.6$ ft. per second.

EXAMPLE.—If the shaft mentioned in the above problem is 1608 ft. deep, how long will it take a stone to fall from top to bottom?

Solution.—$t = \frac{v}{g}$ or $t = \sqrt{\frac{2h}{g}}$.

$$t = \sqrt{\frac{2h}{g}} = \sqrt{\frac{1608 \times 2}{32.16}} = \sqrt{100} \text{ or 10 seconds.}$$

EXAMPLE.—If a falling body has a velocity of 321.6 ft. per second, how long had it been falling at that instant?

Solution.—$t = \frac{v}{g}$. $t = \frac{321.6}{32.16} = 10$ seconds.

EXAMPLE.—A stone dropped down a shaft has a velocity of 321.6 feet when it strikes the bottom, how deep is the shaft?

Solution.—

$$h=\frac{v^2}{2g}=\frac{321.6\times321.6}{2\times32.16}=\frac{103426.56}{64.32}=1608 \text{ ft., depth of shaft.}$$

EXAMPLE.—A body falls down a shaft which is 1608 feet deep, what will be its velocity at the end of the fall?

Solution.—$v=\sqrt{2gh}$.

$$v=\sqrt{2\times32.16\times1608}=321.6 \text{ ft., velocity per sec.}$$

EXAMPLE.—How far will a body fall in 10 seconds?

Solution.—$h=\frac{1}{2}gt^2$ or $h=16.08\times t^2$.

$$16.08\times100=1608 \text{ ft.}$$

EXAMPLE.—If a ball is thrown vertically upward with an initial velocity of 321.6 ft. per second, (*a*) how long a time will elapse before it reaches the earth again?

Solution.—$h=\frac{v^2}{2g}$,

$$h=\frac{321.6^2}{64.32}=1608 \text{ ft.}$$

To find the time required to reach a height of 1608 ft.

$$t=\frac{v}{g}=t=\frac{321.6}{32.16}=10 \text{ seconds.}$$

As it will take the same length of time for the ball to fall to the earth the total time consumed in going both directions will be $10\times2=20$ seconds. *Ans.*

QUESTIONS

1. If a stone thrown upward returns to the ground in 4 seconds, how high does it ascend?

2. A cannon ball is fired horizontally from the top of a cliff 200 ft. high. In how many seconds will it strike the plain at the foot of the cliff?

3. Define (*a*) gravitation; (*b*) gravity.

4. What is Newton's law of gravitation?

5. If an iron ball weighs 100 lb. on the surface of the earth, what will it weigh 1000 miles below the surface?

6. What will a 100-lb. ball weigh 1000 miles above the surface of the earth? What will it weigh at the center of the earth?

7. If two plumb lines suspended at different points on the earth's surface were projected through the earth where would they meet?

8. Will an iron ball weighing 2 lb. fall with a greater velocity than a smaller ball weighing 1 lb.?

9. How far will a freely falling body fall in the first second? What will be its velocity at the end of the first second?

10. A rifle ball is shot vertically upward with a velocity of 1500 ft. per second. In what time will it reach the ground, neglecting the friction of the air?

11. How far must a ball fall in order to acquire a velocity of 321.6 ft. per second?

12. A stone dropped down a shaft strikes the bottom in 4 seconds. What is the depth of the shaft?

13. A stone falls down a shaft 400 ft. deep. In what time will it strike the bottom?

14. Explain what is meant by accelerating force, and at what velocity will it cause a freely falling body to move at the end of the first second of its fall?

15. Why does a balloon ascend in the air?

16. Why does not the attraction of the earth cause fire damp to lodge in low places in a coal mine?

17. When we speak of the weight of a body to what do we refer?

18. Why is it a body has no weight at the center of the earth?

19. A stone 1 cubic foot in volume and weighing 180 lbs. is under water. If a man lifts the stone while under water what weight does he lift?

20. What is the velocity of a freely falling body at the end of 12 seconds?

21. If a stone thrown vertically upward reaches its maximum height in 2 seconds in how many seconds will it fall to the starting point?

CHAPTER IV

LIQUIDS AND LIQUID PRESSURE

25. Liquids offer great resistance to forces tending to diminish their volume. Water is reduced only 0.00005 of its volume by a pressure of one atmosphere. A gas is reduced to one-half its volume by the same pressure.

The case of sea-water is of special interest on account of the influence of its compressibility upon the ocean level. Tait, in his extended investigation of this property in connection with the deep-sea exploration, computed the loss of volume due to the compression of each layer of ocean water by the superincumbent mass, and found the level of the sea to be more than 600 ft. below that which would exist in the case of a strictly incompressible fluid.

26. Pressure on the Side of a Vessel.—When a liquid is contained in a vessel, the sides being vertical, the pressure at any point of a side depends upon its distance from the surface of the liquid. The total pressure on the sides of the vessel is the sum of all these pressures, which vary from zero at the surface to the maximum at the bottom.

Rule.—The pressure of a liquid upon any submerged surface is equal to the weight of a column of the liquid having the area of the surface for its base, and the depth of the center of gravity of the given surface, below the surface of the liquid, for its height. This rule applies to all submerged surfaces whether vertical, horizontal or inclined, plane or curved. If the surface is the horizontal base of the vessel the height of the column will be the total depth of the liquid.

Example.—A vessel is filled with water. Its base is 2 ft. by 2 ft. and 5 ft. high. What is the total pressure on the base?

Solution.—$5 \times (2 \times 2) \times 62.5 = 1250$ lbs. A cubic foot of water weighs about 62.5 lbs. or 1000 ozs.

Note.—In plane surfaces the center of gravity is the center of area. The center of gravity of a triangle is a point two-thirds of the distance from any angle to the middle point of the opposite side. The pressure per square inch due to any head of water may be found by multiplying the head or vertical height of the water by .434.

This number is obtained as follows: $62.5 \div 144 = .434$.

Example.—What is the pressure per square inch on the bottom of a column standing full of water, the vertical height being 500 ft.?

Solution.—$.434 \times 500 = 217$ lbs.

27. Specific Gravity, or Relative Density.—The density of a body depends both upon its mass and its volume. If we were to select some one substance as a standard and compare the density of every other substance to that standard, we should obtain a set of results called the relative densities of substances. The most suitable standard is water, therefore it is used for the purposes of determining the density or specific gravity of solids and liquids. The density of water being 1, the weight of any solid or liquid can be readily found if the specific gravity of the solid or liquid be known.

Example.—If the specific gravity of anthracite coal is 1.4, what is its weight per cubic foot?

Solution.—As the relative densities of water and coal are as 1 : 1.4, meaning that the coal is 1.4 times the weight of water, therefore, as water weighs 62.5 lbs. per cu.ft., a cubic foot of the coal will weigh $62.5 \times 1.4 = 87.5$ lb.

28. How to Find the Specific Gravity.—As the density

of water varies with its temperature as well as with its purity, the temperature 4° C. or 39° F. is taken for the standard density because the density of water is greatest at that temperature. In order to get the most accurate results, distilled water at the temperature given must be used.

DEMONSTRATION.—Weigh a piece of coal in the air and note its weight; weigh again, letting the coal hang in a vessel of water, and the scale will be found to read less. The operation may be expressed by the following formula:

$$\text{Sp.gr.} = \frac{\text{Weight of the body in air}}{\text{Difference of the weight in water and air}},$$

or

$$\text{Sp.gr.} = \frac{W}{W-W''}.$$

In this example W is the weight of the body in air, W'' its apparent weight in water.

EXAMPLE.—A piece of coal weighs 48 ozs. in the air and weighs 9 ozs. in water, what is its specific gravity?

Solution.—$\frac{48}{48-9} = 1.23$ sp.gr.

29. How to Find the Specific Gravity of Bodies Lighter than Water.—If the body be lighter than an equal body of water and will not sink, it must be fastened to a heavy body in order to submerge it. The specific gravity can then be found as follows:

Weigh the body in air (W), then weigh a heavy sinker in water and call its apparent weight S. Tie the sinker to the body and weigh them both in water. Call the apparent weight W''. Compute the specific gravity from the formula

$$\text{Sp.gr.} = \frac{W}{W+(S-W'')}.$$

Law of Floating Bodies.—A floating body displaces a volume of liquid that has the same weight as the floating body.

Example.—A piece of wood weighs 4 ozs. in air (W), a sinker weighs 5 ozs. in water (S), and the two when tied together and submerged weigh 3 ozs. (W''). It is noticed that the wood not only displaces its own weight of water, but buoys up 2 ozs. of the weight of the sinker; therefore the wood displaces 4+2 ozs. of water, hence its specific gravity is

$$\frac{4}{4+(5-3)}=\frac{4}{6}=.67.$$

30. How to Find the Specific Gravity of Liquids.—The specific gravity is accurately obtained by means of the specific gravity bottle. Any bottle with a small neck having a fixed mark around it can be used. First, weigh the bottle when empty (a); then fill with water to the fixed mark and weigh (b). The difference will be the weight of the water ($b-a$). Fill the bottle with the liquid of which the specific gravity is required and weigh (c); the difference ($c-a$) gives the weight of the same volume ot the liquid; then the specific gravity will be

$$\frac{\text{Weight of liquid}}{\text{Weight of equal volume of water}}=\frac{c-a}{b-a}.$$

Example.

	Grammes
Bottle+water	65
Bottle	15
Weight of water	50
Bottle+calcium chloride solution	75
Bottle	15
Weight of solution	60

Therefore the specific gravity or relative density of the calcium chloride solution $= \frac{60}{50} = 1.2$ (taking water as 1).

For practical purposes this method would be slow and tedious, and in such cases the hydrometer is employed. This instrument (Fig. 4) consists of a bulb attached to a long stem and is weighted at the bottom with mercury or small lead shot so that it will float upright in liquid. The stem is graduated, usually with a paper scale inside the glass. The reading on the stem corresponding to the level of the liquid in which the hydrometer is inserted can be easily read.

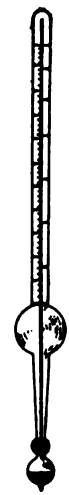


FIG. 4.

The densities and specific gravities in table A are averages of results found by different observers.

By means of tables of specific gravities the weight of a body may be calculated when its volume is known, and conversely the volume when its weight is known.

QUESTIONS

1. Why do liquids buoy up objects immersed in them?
2. State the law of floating bodies.
3. A certain bottle when filled with water weighs 156 gms., when filled with an oil it weighs 148 gms. If the empty bottle weighs 73 gms. find the specific gravity of the oil.
4. A boat displaces 580 cu.ft. of water; find the weight of the boat.
5. A tank 5 ft. deep and 10 ft. square is filled with water. What is the pressure on the bottom of the tank? What on one side?

TABLE A

	Density Sp.gr.	Density in Lbs. per Cu.ft.
Coal, anthracite (varies)	1.5	93.75
Charcoal (oak)	0.57	35.6
Ice	0.917	57.3
Sandstone	2.35	146.8
Aluminum	2.57	160.6
Glass	2.60	162.5
Quartz	2.65	165.6
Marble	2.65	165.6
Granite	2.75	171.8
Iron (gray cast)	7.08	442.5
Zinc (cast)	7.10	443.7
Tin (cast)	7.29	455.6
Iron (wrought)	7.85	490.6
Brass (yellow)	8.44	527.5
Brass (red)	8.60	537.5
Nickel	8.60	537.5
Copper (cast)	8.88	555.0
Silver (cast)	10.45	653.1
Lead (cast)	11.34	708.7
Mercury	13.6	850.0
Gold	19.3	1206.2
Platinum	21.45	1340.6
Water (pure 39° F.)	1.00	62.5

6. How high must the reservoir of a city's water system be above any point to produce a pressure of 50 lbs. per square inch at that point?

7. What is the vertical depth of a column of water which counterbalances a column of mercury 30 ins. deep when the liquids are placed in the U-tube?

8. Why does a hydrometer float vertically in a liquid?

9. A boy can lift 75 lbs. How many cubic inches of coal, the sp.gr. of which is 1.4, can he lift?

10. A block of wood is 1 ft. square and 2 ft. long. Its sp.gr. is .65. How much pressure would be required to keep it under water?

11. How do you find the specific gravity of a liquid?

12. How do you find the specific gravity of a solid which is lighter than water?

13. Which offers the greater resistance to compression, liquids or gases?

14. If a cubic foot of anthracite coal weighs 90 lbs. what is its specific gravity?

15. A cubic foot of sandstone (sp.gr. 2.35) is suspended in water by a rope. What is the tension on the rope? What will it be when it is lifted from the water?

16. A shaft mine 500 feet deep is allowed to fill with water. A certain section of the mine was squeezing prior to the water entering. To what extent will the water aid in stopping the squeeze?

17. If a piece of anthracite coal weighs 50 ozs. in the air and its apparent weight in water is 15 ozs., what is the specific gravity of the coal, and what is its weight per cubic foot?

18. If a body lighter than water weighs 15 ozs. in the air and a sinker weighs 25 ozs. in water and the body and the sinker fastened together weigh 20 ozs. in water, what is the specific gravity of the body?

19. If the weight of a certain liquid is 10 ozs. and the weight of an equal volume of water is 12 ozs., what is the specific gravity of the liquid?

20. An engineer reporting on a certain tract of coal land discovered that 180 acres contained coal, the seam being flat and 7 feet thick throughout the entire property. How many tons of coal are on this property if the specific gravity of the coal is 1.4?

21. A block of wood 1 ft. square and 2 ft. long is pushed down into water until its upper side is 6 ins. below the surface. What is the upward pressure upon the bottom of the block? What is the downward pressure of the

water on the top of the block? How much pressure is required to keep the block in place if its specific gravity is .65? How much pressure would be required to keep it at a depth of 2 ft.? *Ans.* 187.5 lbs., 62.5 lbs., 43.75 lbs., 43.75 lbs.

22. A cake of ice 6 ft. square and 2 ft. thick is floating on a lake. How much will it settle in the water if a man weighing 180 lbs. stands upon it? *Ans.* .96 inch.

CHAPTER V

HEAT

THE commonly used unit to measure the quantity of heat generated by the burning of coal or other substance is called the British Thermal Unit (B.T.U.). It is equivalent to the amount of heat required to raise the temperature of 1 lb. of water 1 degree of the Fahrenheit scale, or 1 B.T.U. is equivalent to 778 foot-pounds.

When heat is added to a body, whether solid, liquid or gaseous, the vibration of the molecules composing the body increases. This increased molecular motion will require an increased space between the molecules, and the body grows larger in volume—that is, it expands—and cooling a body will diminish its molecular motion and reduce its volume. The vibratory movement will cease only when a body is deprived of all its heat.

Changes in temperature are detected and measured by the thermometer. To determine the actual amount of change in temperature in any case and to make it possible to compare the records of one thermometer with those of another, the thermometers must be similarly constructed. To do this we must have one or more easily determined temperatures, called the FIXED POINTS. (1) Careful experimenting has shown that the temperature at which pure ice melts is practically constant, and (2) that the temperature of steam as it comes from boiling water is likewise constant when the pressure upon the water is constant. Then to establish the fixed points the bulb and part of the stem of the thermometer are filled with mercury and are placed in a vessel containing finely

broken ice and allowed to remain until there is no further change in the final position of the top of the mercury. The top of the mercury is then marked; this point is called the freezing-point of water or the melting-point of ice. The thermometer is then put into a steam generator and left until the mercury ceases to expand; this point is then marked and is called the boiling-point. On the Fahrenheit thermometer the freezing-point of water is marked 32 degrees and the boiling-point 212 degrees. On this scale the difference between the two fixed temperatures is divided into 180 degrees.

The centigrade scale differs from the Fahrenheit in making the freezing-point 0° and the boiling-point 100°, the space between being divided into 100 equal parts. This thermometer is the one in general use among scientific men.

Water boils when its vapor escapes with sufficient pressure to overcome the pressure of the atmosphere upon its surface. Hence the boiling-point depends upon the pressure of the atmosphere or the vapor within a vessel such as a steam boiler. The boiling-point is lower as the pressure is decreased and higher as the pressure is increased. Warm water will boil under the receiver of an air pump or on top of a high mountain, the decreased pressure allowing the free movement of the molecules. At a point in South America, 9350 ft. above sea level, water boils at such a low temperature that it is not hot enough to cook potatoes.

31. Exception to the General Rule of Expansion.—Generally speaking water expands and contracts in the manner common to all liquids, but between the temperatures (32° and 39° F.) it presents a remarkable and most important exception. If water at the freezing-point is warmed its volume steadily decreases until 39° F. is reached, but when it is further heated water expands as other liquids do, up to its boiling-point.

Conversion of thermometer readings from one scale to another:

C.° to F.°, multiply by 9, divide by 5, add 32.

F.° to C.°, subtract 32, multiply by 5, divide by 9.

EXAMPLE.—Convert 350° C. into the corresponding Fahrenheit reading.

Solution.—$F.° = \frac{350 \times 9}{5} + 32 = 662°.$

EXAMPLE.—Convert 662° F. into the corresponding centigrade reading.

Solution.—$C.° = \frac{(662-32) \times 5}{9} = 350°.$

The temperature of a melting solid remains unchanged from the time melting begins until the body is entirely melted.

TABLE B

TABLE OF AVERAGE MELTING-POINTS

Ice	0°	C.	or	32.00° F.
Sulphur	115.1°	C.	or	239.18° F.
Lead	326	C.	or	618.8 F.
Silver	950	C.	or	1742 F.
Copper	1100	C.	or	2012 F.
Iron	1500	C.	or	2732 F.
Platinum	1900	C.	or	3452 F.
Cast iron (gray)	1275	C.	or	2327 F.
Steel	1375	C.	or	2507 F.

TABLE C

APPROXIMATE TEMPERATURES

Just glowing in the dark, about	525°	C.	or	977° F.
Dark red	700	C.	or	1292 F.
Cherry red	910	C.	or	1670 F.
Bright cherry red	1000	C.	or	1832 F.
Orange	1160	C.	or	2120 F.
White	1300	C.	or	2372 F.
Dazzling bluish white	1500	C.	or	2732 F.
Bunsen flame	1500	C.	or	2732 F.
Electric arc	3500	C.	or	6332 F.

TABLE D

AVERAGE TEMPERATURES AT WHICH THE FOLLOWING GASES WILL IGNITE

Carbon monoxide....................	CO,	1240 F.
Hydrogen..........................	H_2,	1077 F.
Methane...........................	CH_4,	1212 F.
Ethane............................	C_2H_6,	1140 F.
Ethylene..........................	C_2H_4,	1124 F.
Acetylene.........................	C_2H_2,	970 F.

The above gases react with oxygen in complete combustion as follows:

$$2CO+O_2=2CO_2$$
$$2H_2+O_2=2H_2O$$
$$CH_4+2O_2=CO_2+2H_2O$$
$$2C_2H_6+7O_2=4CO_2+6H_2O$$
$$C_2H_4+3O_2=2CO_2+2H_2O$$
$$2\,C_2H_2+5O_2=4CO_2+2H_2O$$

If the chemical equation expressing a reaction is known, it is possible to calculate the relative weights of the substances concerned in the reaction. By means of the equation expressing the reaction that takes place in the complete combustion of methane in oxygen, it is possible to calculate the weight of oxygen required to completely burn a given weight of the gas; also the weight of the gases due to combustion; thus,

$$CH_4+2O_2=CO_2+2H_2O.$$

Relative weight

$$16+64=44+36.$$

Hence from the above relative weights it is seen that 64 pounds of oxygen are required to completely burn 16 pounds of methane, or 4 pounds of oxygen will completely burn 1 pound of methane.

In like manner the number of pounds of oxygen required to completely burn any number of pounds of the combustible gases in the foregoing table can be calculated.

EXAMPLE.—How many pounds of air will be consumed in the complete combustion of 150 lbs. of methane?

Solution.—Write the chemical equation expressing the reaction that takes place when methane is completely burned in air: thus,

$$CH_4+2O_2+8N_2=CO_2+2H_2O+8N_2.$$

Relative weight $16+64+224=44+36+224$.

As the oxygen and nitrogen in the above equation constitute the air, then the relative weight of air required to burn the methane is $64+224=288$. Hence if it requires 288 lbs. of air to completely burn 16 lbs. of methane it will require $\frac{288}{16}=18$ lbs. of air to completely burn 1 lb. of methane, and to burn 150 lbs. of methane it will require $150\times18=2700$ lbs. of air.

32. A freezing mixture can be made by mixing 1 part of salt with 3 parts of snow or cracked ice. The ice in contact with the salt is melted, the heat necessary for the melting being withdrawn from the objects near by. The salt is dissolved and the temperature falls to the freezing-point of the salt solution, which is lower than that of water. In this manner substances are frozen, for example ice cream.

QUESTIONS

1. What effect (*a*) does expansion always have upon the density of a body? (*b*) Contraction? (*c*) Name an important exception to the general rule that expansion accompanies a rise in temperature.

2. What are the fixed points (*a*) on a Fahrenheit thermometer? (*b*) On a centigrade thermometer? (*c*) How are they marked?

3. Why does ice float in water?

4. Is boiling water over a gas flame receiving any heat?

5. If the bulb of a thermometer be plunged into hot water the mercury at first falls; why?

6. How is it possible to heat water above the ordinary boiling-point?

7. Convert (*a*) 0° C. into the corresponding Fahrenheit reading; (*b*) 212° F. into the corresponding centigrade reading.

8. From the time a piece of cast iron starts to melt until it is all melted does the temperature change?

9. Do water pipes burst when they freeze or when they are thawed?

10. Explain why water boils at a lower temperature under reduced pressure.

11. A piece of ice is floating for a time in warm water. Does the water lose heat? Does the ice receive heat? Does the temperature of the water change? Does the temperature of the ice change?

12. What is the temperature of the Bunsen flame?

13. When a body expands due to a rise in temperature, do the molecules increase in size?

14. Why will water boil at a lower temperature on a high mountain than at sea level?

15. When will the vibratory movement of the molecules of which a body is composed cease?

16. At what temperature is water at its greatest density?

17. Explain why the specific gravity of ice is less than water.

18. Convert (*a*) 32° F. into the corresponding centigrade reading; (*b*) 60° C. into the corresponding Fahrenheit reading.

19. Seventy-six degrees is called summer temperature on the Fahrenheit thermometer. What will be its reading on the centigrade thermometer?

CHAPTER VI

GASES

33. The Atmosphere.—The earth is surrounded by a great mass of gas commonly known as the ATMOSPHERE or AIR. The estimated height to which the atmosphere extends has not been definitely fixed, but observation on meteors show that it really extends to a height of at least 100 miles, and indeed at that height it is sufficiently dense to cause the rapid combustion of a meteor passing through it. This great volume of gas rests upon the earth. The weight of the whole mass is such that it presses on every square inch of the earth's surface at sea level with a weight equal to 14.7 lbs. At higher elevations the pressure is not so great. The pressure of the entire mass of the whole atmosphere may be approximately found by multiplying the number of square inches on the whole surface of the earth by 14.7. In round numbers we might say that it is five thousand million of millions of tons.

34. Composition of the Atmosphere.—Pure dry air is chiefly a mixture of oxygen, nitrogen and carbon dioxide, containing nearly four volumes or parts of nitrogen to one part of oxygen. Figures that are still more exact, and which are frequently used by the chemist when calculating the amount of oxygen in a given volume of air, are as follows:

	Per Cent.
Carbon dioxide (CO_2)	0.03
Oxygen (O_2)	20.93
Nitrogen (N_2)	79.04

These percentages are those commonly used and refer to parts by volume—that is, 100 cubic feet of air contain 0.03 cu.ft. of carbon dioxide, 20.93 cu.ft. of oxygen and 79.04 cu.ft. of nitrogen. By weight the percentages of oxygen and nitrogen are different, for in 100 lbs. of dry air there are approximately 23 lbs. of oxygen and 77 lbs. of nitrogen. Ordinary air is not perfectly dry, but contains some water vapor.

Besides oxygen, nitrogen and carbon dioxide, air contains five so-called rare gases which contribute about 1 per cent of the total volume. These gases are about the same as nitrogen and are considered as nitrogen in most calculations.

All of the gases found in pure air are without color, smell or taste. Pure dry air contains oxygen and nitrogen in the same proportions by volume all over the globe, at either sea level or high altitudes.

35. Oxygen Consumed in Breathing.—An adult person, at rest, breathes in about 400 cu.ft. of air every twenty-four hours, or about 83 cu.ft. of oxygen; this amount is not, however, wholly consumed. Air which has been breathed contains, after removal of the moisture, 3.5 to 4.5 per cent of carbon dioxide and 15.5 to 17 per cent of oxygen. When walking more oxygen is being used up in the lungs, and still more while running or doing hard physical work.

Ordinarily, respiration takes place about eighteen times per minute, but exertion increases this rate. The breathing of air deficient in oxygen produces the same effect as exertion.

Oxygen is slightly soluble in water, 25 volumes of water will absorb one volume of oxygen.

36. Atoms and Molecules.—We often speak of atoms as if an atom of matter could exist. We do so simply because such an expression helps to describe and interpret

chemical action. Atoms do not as a rule exist in the uncombined state. As soon as atoms are freed from combination they at once unite with some other atom or atoms. When atoms unite the combination is called a MOLECULE. Hence a molecule is formed by the chemical union of two or more atoms. The atoms forming a molecule may be like or unlike. If the atoms in a molecule are atoms of the same element or kind, then the molecule is a molecule of an element; but if the atoms of different elements are combined, then the molecule is the molecule of a compound. All matter consists of molecules and the molecules are made up of atoms. We may define an ATOM as the smallest conceivable division of an element, and a MOLECULE as the smallest part of a compound, or of an element which can exist in a free state and manifest the properties of the compound. Thus the smallest particle of marsh gas that can exist is a molecule of marsh gas, but a molecule of marsh gas contains smaller particles still, viz., atoms of carbon and hydrogen.

37. Elements.—An elementary body consists of a simple substance which cannot be analyzed or reduced to parts that have properties other than those peculiar to itself. An element is a substance composed wholly of like atoms; oxygen, nitrogen, hydrogen, gold, silver, iron, etc., are all elements neither of which can be divided chemically into two or more substances; other substances can be added to them, but we cannot get simpler substances from them.

38. Density.—Density is compactness of mass and has reference to the amount of matter in a given volume. When the density of a gas is spoken of it is understood to be compared with hydrogen gas as a standard taken as 1. Thus the density of air is 14.4 and of oxygen 16.0. That is, air and oxygen are respectively 14.4 and 16 times as heavy as hydrogen.

TABLE E

TABLE OF THE MOST IMPORTANT ELEMENTS

Name.	Symbol.	Approximate Atomic Weight.
Oxygen	O	16
Nitrogen	N	14
Hydrogen	H	1
Carbon	C	12
Sulphur	S	32
Iron	Fe	56
Lead	Pb	207
Gold	Au	197
Copper	Cu	63.5
Chlorine	Cl	35.4
Calcium	Ca	40
Aluminium	Al	27
Mercury	Hg	200
Nickel	Ni	58
Rhodium	Rh	103
Silver	Ag	108
Sodium	Na	23
Tin	Sn	119
Tungsten	W	184
Zinc	Zn	65

39. Specific Gravity.—When the specific gravity of a gas is mentioned it is understood that the comparison is made with air as a standard. Thus the specific gravity of carbon dioxide is 1.527 and marsh gas 0.555, one being approximately $1\frac{1}{2}$ times as heavy, and the other half as heavy as air, the specific gravity of air being 1. Specific gravity is the measure of the density of a body.

The density or specific gravity of all gases is affected by the temperature and pressure; if the temperature be increased the density is reduced and if the temperature be decreased the density is increased. The pressure also affects the volume and therefore the weight, if the gas be free to expand or contract. Hence the comparison of all

TABLE F

Common Name.	Chemical Name.	Symbol.	Formula.	Atomic Weight.	Calculated Specific Gravity Air 1.	Weight per Cu.ft. in Lbs. T. 30° F., Bar. 30″.
	Hydrogen	H	....	1	......	0.005645
	Carbon	C	....	12	......	0.0677
	Nitrogen	N	....	14	......	0.0790
	Oxygen	O	....	16	......	0.0903
	Sulphur	S	....	32	......	0.1806
Air	....	CN_4	$\frac{16+(4\times14)}{5}=$	14.4	1.0	0.0813
Marsh gas	Methane	CH_4	$\frac{12+(4\times1)}{2}=$	8	.555	0.0451
Fire damp	Marsh gas mixed with air	.....	....	13.8	.9583	0.0779
Black damp	Carbon dioxide	CO_2	$\frac{12+(2\times16)}{2}=$	22	1.527	0.1242
White damp	Carbon monoxide	CO	$\frac{12+16}{2}=$	14	.972	0.0790
Stone damp	Sulphureted hydrogen	H_2S	$\frac{(2\times1)+32}{2}=$	17	1.1805	0.0959
Ethane	Ethane	C_2H_6	$\frac{(2\times12)+(6\times1)}{2}=$	15	1.0416	0.0846
Ethylene	Ethylene	C_2H_4	$\frac{(2\times12)+(4\times1)}{2}=$	14	.972	0.0790
Acetylene	Acetylene	C_2H_2	$\frac{(2\times12)+(2\times1)}{2}=$	13	.9028	0.0734

NOTE.—Air is a mechanical mixture and not a chemical compound, therefore it cannot be truly represented by a formula, but it is found convenient to use the approximate formula ON_4 in order to make comparison with the mine gases.

densities and specific gravities is understood to have been made at the same standard temperature and pressure, namely, 60° F. and 30″ barometer.

The units of measure are as follows:

For solids and liquids, as has been stated, 62.5 lbs., the weight of 1 cu.ft. of water. For gases, .0766, the weight of 1 cu.ft. of air (temperature 60° F., barometer, 30″).

Example.—If the specific gravity of carbon dioxide is 1.527, what is the weight of a cubic foot of the gas?

Solution.—$1.527 \times .0766 = .1169$.

Example.—Find the weight of 5 cu.ft. of marsh gas at a temperature of 60° F. and a pressure due to 30 ins. of barometer, the gas having a specific gravity of 0.559.

Solution.—$0.559 \times .0766 \times 5 = .2141$.

Rule 1.—To find the specific gravity of a solid or liquid divide its weight per cubic foot by the weight of a cubic foot of water (62.5 lbs.).

Rule 2.—To find the weight per cubic foot of a solid or liquid multiply its specific gravity by the weight of a cubic foot of water (62.5 lbs.).

In Table F is shown a comparison of several gases, most of which are met with in mines, all of which the student should commit to memory:

RULES

To Find the Specific Gravity of a Gas

1. $\text{Sp.gr.} = \dfrac{\text{atomic weight}}{14.4}$.

2. $\text{Sp.gr.} = \dfrac{\text{weight per cubic foot of a gas}}{\text{weight per cubic foot of air}}$.

To Find the Weight per Cubic Foot of a Gas

1. Weight per cubic foot = atomic weight $\times$ .005645.
2. Weight per cubic foot = sp.gr. $\times$ weight of cu.ft. of air.

It should be noticed that the weight of solids bears no relation to the atomic weight; the reason for this is, that like volumes of solids or liquids do not necessarily contain the same number of molecules. A solid may have an atomic weight of 5 and yet weigh more per cubic foot than another solid having an atomic weight of 6.

QUESTIONS

1. If the specific gravity of a gas is known, how do you find the weight per cubic foot?
2. Why do you not feel the pressure of the atmosphere?
3. What is the difference between an atom and a molecule?
4. What is an element?
5. What is the atomic weight of hydrogen, carbon, nitrogen, oxygen and sulphur?
6. If the specific gravity of carbon dioxide is 1.527, what does it weigh per cubic foot?
7. What is the weight of a cubic foot of oxygen?
8. What is the specific gravity of ethane and what is its weight per cubic foot?
9. If the specific gravity of coal is 1.45, what is the weight of 100 cu.ft. of coal?
10. Which is the more dense, marsh gas or carbon dioxide?
11. If a cubic foot of sandstone weighs 180 lbs., what is its specific gravity?
12. What is fire damp?
13. Will marsh gas or methane explode?
14. What are the three forms of matter?

15. What are the properties of ethane gas?

16. What is black damp?

17. What is the composition of air?

18. If a cubic foot of hydrogen weighs .0056 lb., what is the weight of a cubic foot of carbon?

19. If two or more atoms unite what is the combination called?

20. What is meant when it is said that carbon dioxide is more dense than marsh gas?

21. Is the density or specific gravity of a gas affected by the temperature and pressure?

22. If the weight of a cubic foot of coal is 90 lbs., what is its specific gravity?

23. What is the pressure per square inch due to the atmosphere at sea level?

24. If the barometer reading is 28 inches, what is the pressure per square inch?

CHAPTER VII

GASES

40. Chemical Compounds.—In chemical compounds the combining atoms unite in definite fixed proportions. The elements which make up a chemical compound are called COMPONENTS. Chemical compounds have three essential characteristics: (1) their components are held together by chemical attraction. The hydrogen and oxygen, which are the components of water, cannot be separated unless their attraction for each other is overcome by heat or some other agent. (2) In any given chemical the components are always in the same ratio. Thus pure water always contains eight parts (by weight) of oxygen and one of hydrogen. (3) In chemical compounds the identity of the components is lost.

41. Mechanical Mixtures.—The molecules of the different substances forming the mixtures may be present in any proportion. Mixtures must not be confused with chemical compounds. The parts of a mixture may vary in nature as well as in proportion; they are also held together loosely and may often be separated by some mechanical operation, as filtering or sifting. The atmosphere is a good example of mechanical mixture. The proportion of oxygen and of nitrogen is not fixed, but varies between small limits, which may be detected by accurate analysis.

42. Chemical Symbols.—To facilitate the writing of chemical equations the elements are usually denoted by their first letter. Thus H is the symbol for hydrogen, O for oxygen. Since several elements have the same initial

letter, the symbol for some elements contains two letters. Thus C is the symbol for carbon while the symbol for calcium is Ca. It should be remembered that the symbols represent single atoms. Thus O represents one atom of oxygen; C represents one atom of carbon. If more than one atom is to be designated the required number is placed before the symbol as follows:

2C means 2 atoms of carbon,
4O means 4 atoms of oxygen,
3H means 3 atoms of hydrogen.

Chemical compounds are expressed by a combination of symbols representing atoms, thus:

CH_4 is the formula for marsh gas, meaning that the gas is composed of one atom of carbon and four of hydrogen. If we wish to designate several molecules the proper number is placed before the formula, thus:

$2CH_4$ means 2 molecules of marsh gas.

A group of symbols designed to express the composition of a compound is called a CHEMICAL FORMULA. Thus H_2O is the formula for water, similarly CO_2 is the formula for carbon dioxide.

43. Atomic Weight.—Atomic weight means RELATIVE WEIGHT only; it does not mean pounds or ounces or any other denomination. An atom of hydrogen is taken as a standard. Hydrogen being the lightest known element in nature, 1 is therefore adopted as its atomic weight. Thus when we say the atomic weight of oxygen is sixteen we mean that an atom of oxygen weighs 16 times as much as an atom of hydrogen.

Different atomic weights are sometimes given for the

same element. This is due to the disagreement among chemists as to the accuracy of certain results. The method of finding the atomic weight is explained in Chapter VI.

44. Molecular Weights.—The molecular weight is the sum of the weights of the atoms in a molecule; thus a molecule of carbon dioxide (CO_2), contains one atom of carbon (the atomic weight of which is 12), and two atoms of oxygen (the atomic weight of oxygen being 16). Therefore the molecular weight of CO_2 is $12+(16\times2)=44$.

When the formula is given the molecular weight of any compound can be found by adding the atomic weights. Since the formula of a compound expresses its composition, it is possible to calculate the percentage composition of weight. The formula for marsh gas is CH_4; the percentage of weight of each element composing the gas is as follows:

1 atom of carbon	$=12$
4 atoms of hydrogen (4×1)	$=\ 4$
1 molecule CH_2	$=16$

It is readily seen that the carbon forms $\frac{12}{16}$ or $\frac{3}{4}$ or 75 per cent by weight of marsh gas, and hydrogen $\frac{4}{16}$ or $\frac{1}{4}$ or 25 per cent of the gas.

Example.—What per cent of the weight of carbon dioxide gas is oxygen?

Solution.—Carbon dioxide (CO_2) contains 1 atom of carbon and 2 atoms of oxygen. The molecular weight is therefore, $12+(16\times2)=44$, of which oxygen forms $\frac{32}{44}$ or $\frac{8}{11}$ or $72\frac{8}{11}$ per cent. Ans.

45. Chemical Equations.—*Chemical reactions are commonly and conveniently represented by equations, placing the sum of the factors equal to the sum of the products.* Since matter may be changed in its form but cannot be destroyed

the individual atoms of the factors reappear in the products; they are differently arranged, but not one is gained or lost.

Thus when quicklime (CaO) is slaked with water (H_2O) the following equation denotes the chemical action:

$$CaO+H_2O=CaO+H_2O,$$

that is, $Ca(HO)_2$ or Ca_2HO, from which we learn that $40+16=56$ parts by weight of calcium oxide combines with $2+16=18$ parts by weight of water to form $56+18$ parts by weight of calcium hydrate (slaked lime).

Again, when methane or fire damp burns, the chemical reaction is represented by the equation:

$$CH_4+2O_2=CO_2+2H_2O,$$

$$1 \text{ vol.}+2 \text{ vols.}=1 \text{ vol.}+2 \text{ vols.},$$

or

$$1 \text{ cu.ft.}+2 \text{ cu.ft.}=1 \text{ cu.ft.}+2 \text{ cu.ft.},$$

which means that 1 volume of fire damp requires 2 volumes of oxygen for its complete and exact combustion and that the fire damp forms its own volume of carbon dioxide and 2 volumes of water in the form of steam.

46. Humidity of the Air.—The rate at which water evaporates or "objects dry" when exposed to the air depends upon the relative humidity of the air at the time. For example, water appears on the surface of the human body as perspiration. When the relative humidity of the air is low the evaporation of the perspiration is rapid and the cooling effect is sufficient for the needs of the body; but when the relative humidity is high, say 80 to 100 per cent, the perspiration may come freely, but on account of the slow evaporation the cooling effect is small and

we suffer from the excess of heat. Hence the high relative humidity of air in a mine renders it oppressive.

During the warm weather the liability of a dust explosion in bituminous mines is not as great as in the winter time. This is due to the fact that the warm well-saturated air entering the mines in the summer time is lowered in temperature, and thereby contracts, reducing the moisture-holding capacity of the air, by reason of which contraction the moisture in the air is distributed along the passage-ways and saturates the coal dust. The higher the temperature of the air the more water it will absorb. (See Table G.)

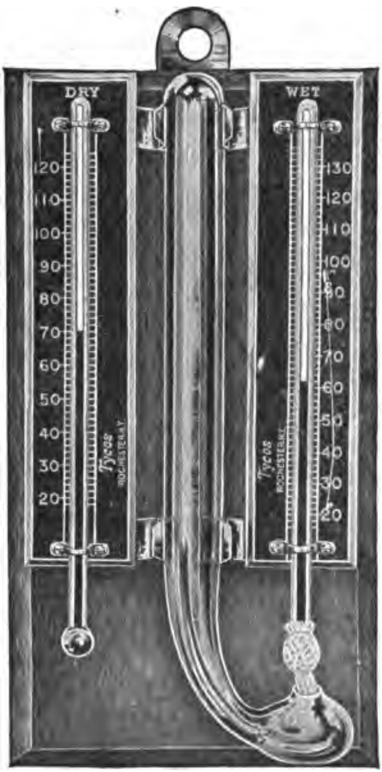


FIG. 5.

The humidity of the mine air also affects the limits at which marsh gas and air will explode. A mixture of marsh gas and air that would just explode when the air is undersaturated would be inexplosive in air saturated with watery vapor.

47. The Hygrometer and Its Use.—The hygrometer is an instrument used for determining the amount of watery vapor in the air; or in other words the relative humidity of the air.

The hygrometer is shown in Fig. 5. It consists of two thermometers placed side by side, the one a dry and the other a wet-bulb. Round the wet-bulb is fastened an absorbent wick the end of which dips into a vessel of water. This keeps the bulb wet and the rate of evaporation affects the temperature of the bulb. If there is little moisture in the air the evaporation takes place rapidly and the wet-bulb thermometer will read considerably lower than the other. The more vapor present in the air the more slowly the water evaporates from the bulb, and consequently the LESS the cooling effect upon it.

Evaporation is always accompanied by loss of heat. It is evident then that the GREATER the difference between the readings of the two thermometers the LESS moisture is present in the air of the mine.

TABLE G

THE WEIGHT OF WATER VAPOR CONTAINED IN SATURATED AIR

Barometer 30 Inches

Temp. Deg. F.	Grains per cu.ft.	Temp. Deg. F.	Grains per cu.ft.
20	1.321	60	5.745
25	1.611	65	6.782
30	1.956	70	7.980
32	2.113	75	9.356
35	2.366	80	10.934
40	2.849	85	12.736
45	3.414	90	14.790
50	4.076	95	17.124
55	4.849	100	19.766

NOTE.— $437\frac{1}{2}$ grains = 1 Av. oz.
7000 grains = 1 Av. lb.

THE WEIGHT OF AQUEOUS VAPOR (ABSOLUTE HU-

MIDITY).—The weight of a cubic foot of aqueous vapor at different temperatures and percentages of saturation is called absolute humidity.

RELATIVE HUMIDITY.—The relative humidity depends on the temperature of the air. If we make moist air cooler its relative humidity will increase without increasing its absolute humidity. If cooled sufficiently its relative humidity will become 100 per cent, which is saturation.

DEW POINT.—The dew point is that temperature of the air at which the invisible moisture (in the air) begins to condense into visible water drops.

Saturated aqueous vapor is but little more than half as heavy as the same volume of dry air under like conditions of temperature and pressure. In all ordinary computations it is assumed that the expansion and contraction of partially saturated aqueous vapor is in accordance with the same laws as apply to air and ordinary gases which do not easily condense to the liquid state.

The density of saturated aqueous vapor is not determined directly from experiment, but is deduced theoretically from the observed fact that two volumes of hydrogen and one of oxygen combine to produce two volumes of water vapor.

The weights of unit volumes of hydrogen, oxygen and dry air are accurately known, from which the specific gravity of aqueous vapor is found to be 0.6221. Liquids in the vapor state obey all the laws of gases.

THE PROPER HUMIDITY.—Dr. H. M. Smith, M.D., in his book on "INDOOR HUMIDITY," says: "It was most interesting and instructive to find that on the perfect days in May and early June, with all the windows open admitting freely the outdoor air, a thermometer stood at 65 to 68 degrees and the hygrometer registered about 60 per cent relative humidity.

"If a room at 68 to 70 degrees is not warm enough for

Table H

RELATIVE HUMIDITY, PER CENT—FAHRENHEIT TEMPERATURES

Pressure = 30.0 Inches

Dry-bulb Reading.	Difference between Dry and Wet Bulbs.																				
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
20	92	85	77	70	62	55	48	40	33	26	19	12	5								
21	92	85	78	71	63	56	49	42	35	28	21	15	8	1							
22	93	86	78	71	65	58	51	44	37	31	24	17	11	4							
23	93	86	79	72	66	59	52	46	39	33	26	20	14	7	1						
24	93	87	80	73	67	60	54	47	41	35	29	22	16	10	4						
25	94	87	81	74	68	62	55	49	43	37	31	25	19	13	7	1					
26	94	87	81	75	69	63	57	51	45	39	33	27	21	16	10	4					
27	94	88	82	76	70	64	58	52	47	41	35	29	24	18	13	7	2				
28	94	88	82	76	71	65	59	54	48	43	37	32	26	21	15	10	5				
29	94	88	83	77	72	66	60	55	50	44	39	34	28	23	18	13	8	3			
30	94	89	83	78	73	67	62	56	51	46	41	36	31	26	21	16	11	6	1		
31	94	89	84	78	73	68	63	58	52	47	42	37	33	28	23	18	13	8	4		
32	95	89	84	79	74	69	64	59	54	49	44	39	35	30	25	20	16	11	7	2	
33	95	90	85	80	75	70	65	60	56	51	46	41	37	32	27	23	18	14	9	5	0
34	95	90	86	81	76	71	66	62	57	52	48	43	38	34	29	25	21	16	12	8	3
35	95	91	86	81	77	72	67	63	58	54	49	45	40	36	32	27	23	19	14	10	6
36	95	91	86	82	77	73	68	64	60	55	51	46	42	38	34	29	25	21	17	13	9
37	95	91	87	83	78	74	69	65	61	57	53	48	44	40	36	31	27	23	19	15	11
38	96	91	87	83	79	75	70	66	62	58	54	50	46	42	37	33	29	25	21	17	14
39	96	92	87	83	79	75	71	67	63	59	55	51	47	43	39	35	31	27	24	20	16
40	96	92	87	83	79	75	71	68	64	60	56	52	48	45	41	37	33	29	26	22	18
41	96	92	88	84	80	76	72	69	65	61	57	54	50	46	42	39	35	31	28	24	20
42	96	92	88	85	81	77	73	69	65	62	58	55	51	47	44	40	36	33	30	26	23
43	96	92	88	85	81	77	73	70	66	63	59	55	52	48	45	42	38	35	31	28	25
44	96	93	88	85	81	78	74	71	67	63	60	56	53	49	46	43	39	36	33	30	26

45	96	93	89	86	82	78	74	71	67	64	61	57	54	51	47	44	41	38	34	31	28
46	96	93	89	86	82	79	75	72	68	65	61	58	55	52	48	45	42	39	35	32	29
47	96	93	89	86	82	79	75	72	69	66	62	59	56	53	49	46	43	40	37	34	31
48	96	93	90	86	83	79	76	73	69	66	63	60	57	54	50	47	44	41	38	35	32
49	96	93	90	86	83	80	76	73	70	67	64	61	57	54	51	48	45	42	39	36	34
50	96	93	90	87	83	80	77	74	71	67	64	61	58	55	52	49	46	43	41	38	35
51	97	94	90	87	84	81	78	75	71	68	65	62	59	56	53	50	47	45	42	39	36
52	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	51	49	46	43	40	37
53	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	52	50	47	44	41	39
54	97	94	91	88	85	82	79	76	73	70	67	64	61	59	56	53	50	48	45	42	40
55	97	94	91	88	85	82	79	76	73	70	68	65	62	59	57	54	55	49	46	43	41
56	97	94	91	88	85	82	79	76	73	71	68	65	63	60	57	55	52	50	47	44	42
57	97	94	91	88	85	82	80	77	74	71	69	66	63	61	58	55	53	50	48	45	43
58	97	94	91	88	85	83	80	77	74	72	69	66	64	61	59	56	54	51	49	46	44
59	97	94	91	89	86	83	80	78	75	72	70	67	65	62	59	57	55	52	49	47	45
60	97	94	91	89	86	83	81	78	75	73	70	68	65	63	60	58	55	53	50	48	46
61	97	94	92	89	86	84	81	78	76	73	71	68	65	63	61	58	56	54	51	49	47
62	97	94	92	89	86	84	81	79	76	74	71	69	66	64	61	59	57	54	52	50	47
63	97	95	92	89	87	84	82	79	77	74	71	69	67	64	62	60	57	55	53	50	48
64	97	95	92	90	87	84	82	79	77	74	72	70	67	65	63	60	58	56	53	51	49
65	97	95	92	90	87	85	82	80	77	75	72	70	68	66	63	61	50	56	54	52	50
66	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	61	59	57	55	53	51
67	97	95	92	90	87	85	83	80	78	75	73	71	69	66	64	62	60	58	56	53	51
68	97	95	92	90	88	85	83	80	78	76	74	71	69	67	65	62	60	58	56	54	52
69	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53
70	98	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	61	59	57	55	53
71	98	95	93	90	88	86	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54
72	98	95	93	91	88	86	84	81	79	77	75	73	71	69	67	65	63	61	59	57	55
73	98	95	93	91	88	86	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55
74	98	95	93	91	89	86	84	82	80	78	76	74	71	69	67	65	63	61	60	58	56
75	98	96	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56
76	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57
77	98	96	93	91	89	87	85	83	81	79	77	74	72	71	69	67	65	63	61	59	57
78	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	62	60	58
79	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60	58
80	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	62	61	59

any healthy person it is because the humidity is too low and water should be evaporated to bring the moisture up to the right degree. In other words water instead of coal should be used to make rooms comfortable when the temperature has reached 68 degrees.

"Humidity causes the temperature, as shown by the thermometer, to vary as much as 35 degrees from the temperature as felt by the body. If it were not for the moisture in the air it would be too cold to live in. The reason for this is that if the air is dry the heat goes through it without warming it. If the air is moist it stops the radiated heat and warms it so that humidity acts as a check and prevents the heat from passing through the air. The dry air allows too much radiation from the body and too rapid evaporation makes us feel cold."

The cooling effect produced by a wind does not necessarily arise from the wind being cooler, for it may, as shown by the thermometer, be actually warmer, but arises from the rapid evaporation it causes from the surface of the skin. Without moisture in the air there would be no life. The lack of humidity causes discomfort, ill health, catarrhs, colds and other diseases of the mucous membrane. It is supposed that colds are taken (in winter) by the sudden change in temperature in stepping out of doors, but as a matter of fact the change in humidity is much more harmful. In buildings heated by steam and hot water, with an average temperature of 70 degrees, the relative humidity averages about 30 per cent; in stepping from this atmosphere to an outside humidity of about 70 per cent the violent change is productive of harm, particularly to the delicate mucous membrane of the air passages. The pneumonia period is the season of artificial heat in living rooms. The relative humidity should never be lower than 60 to 65 per cent.

48. Influence of High Relative Humidity and Temperature.—In hot mines the relative humidity, or proportion of water vapor present is of particular importance, and the amount of physical or mental labor a man can perform is affected thereby. A man begins to feel uncomfortable when the wet-bulb temperature is 60° F., and at a wet-bulb temperature of 70° F. the performing of very little work will increase the bodily temperature.

Professor Haldane found it impossible to stay in an atmosphere at a temperature of 93° F., wet-bulb. The temperature of his body rose 5° after a short time, and he finally had to come out. In a moving atmosphere, however, having a temperature of 80° F., wet-bulb, men can work with comfort; the evaporation produces sufficient cooling effect for the body.

It has been proven by experiment that an atmosphere containing 16 per cent of oxygen and 2 per cent of carbon dioxide can be breathed without any noticeable effect. Discomfort is, however, felt when the wet-bulb temperature of an atmosphere of this composition rises above 60° F. It was further shown that relief was not obtained by a person confined in a closed chamber in which the wet-bulb temperature was 84° F., and while so confined breathed, through a tube, the pure air outside the chamber. The influence of heat and its effect on the human system depends entirely upon the temperature recorded by the wet-bulb thermometer no matter what the dry-bulb might show; the capacity for work, however, is greatly increased if a current of air is passing over the body.

The writer has noticed that the effect of watering a roadway in a mine has been to increase the wet-bulb temperature to such an extent that the ability to perform laborious work was lessened.

By the use of Table H the relative humidity of the air can be determined from the hygrometer readings.

HOW TO FIND RELATIVE HUMIDITY BY THE TABLE

Look in column on left for the nearest degree to the dry-bulb reading, then go horizontally along until the column is reached, on the top of which is the difference between the dry and wet-bulb thermometers, in which column the relative humidity will be found.

EXAMPLE.—The dry-bulb reading is 62°; the wet-bulb 53°; the difference is 9. Find 62° in column on left, run the eye horizontally along the column on top of page until 9 is reached, when the relative humidity will be found to be 54 per cent.

49. Diffusion of Gases.—Fill two jars with gas, one with carbon dioxide and the other with hydrogen, and place them mouth to mouth, the jar containing the heavier gas (carbon dioxide) beneath the jar containing hydrogen; while in this position it would appear that the lighter gas in the upper jar would rest on the heavier gas in the lower jar; it will be found, however, that this is not the case; in a short time the gases will intermix and the composition of the gas in each jar will be the same. Further, these gases will never separate again into a heavy and light layer as they were before mixing.

All gases when in proximity to each other mix or spread one into the other. The greater the difference between the densities of the gases the quicker they mix.

This property of gases mixing will account for the fact that carbon dioxide is not always found on the floor of a mine, but is sometimes well diffused in the atmosphere.

If two liquids which do not act chemically upon each other be mixed and allowed to stand, it will be found after a short time that the heavier liquid has settled to the bottom.

Law of Diffusion of Gases.—The rate of diffusion of gases varies inversely as the square roots of their densities.

Example.—The density of hydrogen being 1, that of carbon dioxide being 22, their relative rates of diffusion will be inversely as $\sqrt{1} : \sqrt{22}$ which is as 1 : 4.69. That is, hydrogen will diffuse 4.69 times as quickly into carbon dioxide as carbon dioxide will diffuse into hydrogen.

Example.—If the density of marsh gas is 8, and of air 14.4, what is the rate of diffusion? *Ans.* 1 : 1.34.

Thus we see from the foregoing examples that 4.69 volumes of hydrogen will diffuse in the same time as 1 volume of carbon dioxide, and 1.34 volumes of marsh gas in the same time as 1 volume of air.

QUESTIONS

1. What is a chemical compound?
2. What is a mechanical mixture?
3. Define atomic weight.
4. What is a chemical symbol and why are they used?
5. What is the molecular weight of carbon dioxide and how is it found?
6. The formula for carbon dioxide is CO_2; in a volume of this gas what part of its weight is carbon?
7. Can matter be destroyed?
8. When we speak of the relative humidity of the air being high what is meant?
9. If the relative humidity of the air entering a bituminous mine is low, in what condition would you expect to find the coal dust?
10. What effect has humidity on the explosive limits of marsh gas and air?
11. Describe the hygrometer. What is it used for?
12. What is meant by diffusion of gases?

13. Which will diffuse into air more quickly, marsh gas or carbon monoxide?

14. When liquids which do not act chemically are mixed what takes place?

15. Will the diffusion of two gases be quicker if the difference between their densities is great or small?

16. What is the difference between relative humidity and absolute humidity?

17. Will evaporation be fast or slow when the relative humidity is high?

18. When are dust explosions more liable to occur in bituminous mines, summer or winter? Why?

19. When evaporation is rapid does the wet-bulb thermometer of the hygrometer rise or fall?

20. What is the specific gravity of saturated aqueous vapor?

21. There are two intake shafts at a mine; the relative humidity of the air in one is 90 per cent and in the other 40 per cent. The depths and other conditions being similar through which will the most air flow? Why?

22. What should be the relative humidity of the air in living rooms?

23. If the dry-bulb of a hygrometer reads 60 degrees and the wet-bulb 55 degrees, what is the relative humidity?

24. A steam jet is placed in an upcast shaft, the temperature is increased 8 degrees and the relative humidity is increased 40 per cent. Does the increased relative humidity assist in increasing the quantity of air? Explain.

25. Will a wet road in a mine dry sooner if the velocity of the air is high or if it is low? Why?

CHAPTER VIII

BAROMETER

50. There are two kinds of barometers in use, namely, the mercurial and the aneroid. The aneroid, owing to its portable form and great sensitiveness in responding to changes in pressure of the atmosphere, is to-day in more general use than any other form of barometer. It will denote a change much quicker than the mercurial barometer.

In measuring altitudes, owing to its portability, sensitiveness and ease with which approximate results may be obtained, it is highly valuable to the engineer and surveyor.

The illustration (Fig. 6) shows the general construction of the movement with its elastic metallic box called the vacuum chamber, *A*.

The chamber is constructed with two circular discs of thin corrugated German silver firmly soldered together at the edges, forming a closed box as shown in Fig. 7. The air is exhausted from this box, which causes the top and bottom discs to close together as shown in Fig. 8. The pressure of the air upon the outside surface of an ordinary size chamber is equal to a force of about 60 lbs.

The vacuum chamber *A* is firmly fixed to the circular metal base *B* by a post upon its center projecting through the base plate.

An iron bridge *C* spans the chamber, resting upon the base plate by means of the two pointed screws, *c′c*.

These screws are used to regulate the tension upon the chamber *A*.

To the bridge *C* is fixed the mainspring *D*, which is forced down by mechanical means sufficient to insert the knife-edge piece, *e*.

As this knife edge is fastened, by means of a central pillar, to the top disc of chamber *A*, the mainspring *D*

FIG. 6.

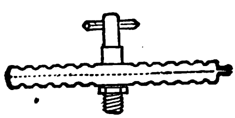


FIG. 7.

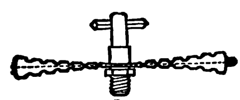


FIG. 8.

when released lifts the upper part of the chamber, drawing the two discs asunder so that the box again has the appearance as shown in Fig. 7.

As this forms a perfect balance (the power of the mainspring opposing the atmospheric pressure upon the vacuum chamber) any variation in air pressure will now be shown by a movement up or down of the elastic chamber. A decrease in pressure will allow the mainspring to overcome the power of the vacuum, the action then being

upwards, and an increase of air pressure will produce the contrary result.

This vertical action of the vacuum chamber is multiplied and converted to a horizontal movement of the indicating hand by a series of mechanical movements.

As there is sometimes a settlement of some of the metal parts and springs which alters the position of the indicating hand, it is advisable, whenever an opportunity offers, to compare the readings of an aneroid with a standard mercurial barometer. If they do not agree the aneroid may be adjusted by turning the small adjusting screw until the indicating hand on the dial coincides with the height of the mercury column.

FIG. 9.

FIG. 10.

In the best made instruments the main lever *G* is made of a composite bar of two metals, steel and brass, the quantity of each metal being altered until it is correctly compensated for any change in temperature. This

averts the necessity of making allowances for changes in temperature, as is necessary in reading a mercurial barometer.

The divisions upon the scale of an aneroid barometer represents inches and fractions of an inch of atmospheric pressure, the scale being determined by comparison with a mercury column as explained.

The words "*storm,*" "*change,*" "*fair,*" etc., upon the dial are simply relatives, as it does not follow that the weather conditions indicated by these words will necessarily exist when the indicating hand of the barometer points to them. The meaning, for example, when the hand points to the word "*fair,*" is that the atmospheric pressure at that time is favorable to fair weather.

The mercurial barometer consists of a glass tube about 34 ins. long. The tube is closed at one end and filled with mercury; it is then inverted with its lower end constantly below the surface of the mercury in a vessel fixed at the bottom. Figs. 9 and 10 show the mercurial and aneroid barometers ready for use.

51. Atmospheric Pressure.—The average pressure of the atmosphere at sea level is 14.7 lbs. per square inch. This is called the pressure of 1 ATMOSPHERE.

If the area of a cross-section of the barometer tube is 1 sq.in. there should be 30 cu.ins. of mercury in a column 30 ins. high. As a cubic inch of mercury weighs .49 lb. the whole column would weigh $30 \times .49 = 14.7$ lbs.

EXAMPLE.—If the barometer reads 28 inches, what is the atmospheric pressure?

Solution.—$28 \times .49 = 13.72$ lbs. per sq.in.

If a liquid less dense than mercury is used the column will be correspondingly longer. Hence, if water be used instead of mercury the column at sea level would be

408 inches, since mercury is 13.6 times as heavy as water.

EXAMPLE.—If the mercury column is 29 inches, what would be the height of a water column under the same pressure?

$$13.6 \times 29 = 394.4 \text{ ins.} \quad \textit{Ans.}$$

The pressure of the atmosphere on the top of a high mountain is less than at sea level and it is greater at the bottom of a shaft than at the top. If the barometer reads 30 inches at the top of a shaft and at the bottom it reads 31 inches, the shaft is about 900 feet deep, as a difference of 900 feet in altitude means a rise or fall of approximately 1 inch of barometer.

52. Use of a Barometer in a Mine.—The barometer is an instrument of great importance in mines where explosive gases are generated; an increase or decrease in the atmospheric pressure is instantly indicated by the aneroid (not so quickly by the mercurial). Hence, in case the barometer drops 1 inch this will mean a reduction of .49 lb. on every square inch of surface in the mine, thereby allowing the occluded gases in the coal to escape more freely.

At some of the anthracite mines of Pennsylvania the barometer is located in a convenient place on the surface and the readings are recorded three times each day. In case the barometer indicates a decrease in pressure, the person in charge of the mine is notified of the impending danger.

53. Use of the Aneroid in Determining Altitudes.—When a compensated barometer is used it is not necessary to make allowance for temperature. Before taking an altitude reading the 0 of the altitude scale should be opposite 31 inches on the barometer dial.

For example, suppose the aneroid indicated a pressure of 29 inches, and if we ascend a hill and the hand (by reason of a decreasing pressure) moves to 25 inches, the method of determining the difference in altitude is as follows: The value of 29 inches with the 0 of the outer rim at 31 is about 1800 feet, while the value of 25 inches under the same conditions is 5850 feet.

5850 − 1800 = 4050, the difference in altitude.

Now suppose the barometer indicates a pressure of 29 inches, but instead of having the 0 feet at 31 inches, we move the milled ring so that the 0 feet is standing opposite 29 inches, and the observer then ascends a mountain until the hand moves to 25 inches the altitude registered will be only 3750 feet, or 300 feet in error.

The graduations on the altitude scale of an aneroid gradually diminish in size. The first inch of pressure, from 31 inches to 30 inches, represents an ascent of about 900 feet, while an inch of pressure, from 26 inches to 25 inches, represents about 1050 feet.

Difference in altitude cannot be accurately determined by means of the barometer in the mine workings, because there is always a difference in pressure between the intake and return airways.

If in case of an exhaust fan ventilating a mine, the barometer is carried through the intake and back through the return to the fan, it will be found that the barometer gradually falls as the distance to the fan decreases.

Stepping from an intake airway through a door to the return airway will cause a fall in the barometer equal to the difference in pressure between the two airways. Under such conditions the barometer might show a difference of

100 feet in elevation, while in reality the elevations of both roads are the same.

Table I

PROFESSOR AIREY'S TABLE OF ALTITUDES

Barometer in Inches.	Height in Ft.	Barometer in Ins.	Height in Ft.	Barometer in Ins.	Height in Ft.	Barometer in Ins.	Height in Ft.
31.00	0	28.28	2500	25.80	5000	23.54	7500
30.94	50	28.23	2550	25.75	5050	23.50	7550
30.88	100	28.18	2600	25.71	5100	23.45	7600
30.83	150	28.12	2650	25.66	5150	23.41	7650
30.77	200	28.07	2700	25.61	5200	23.37	7700
30.71	250	28.02	2750	25.56	5250	23.32	7750
30.66	300	27.97	2800	25.52	5300	23.28	7800
30.60	350	27.92	2850	25.47	5350	23.24	7850
30.54	400	27.87	2900	25.42	5400	23.20	7900
30.49	450	27.82	2950	25.38	5450	23.15	7950
30.43	500	27.76	3000	25.33	5500	23.11	8000
30.38	550	27.71	3050	25.28	5550	23.07	8050
30.32	600	27.66	3100	25.24	5600	23.03	8100
30.26	650	27.61	3150	25.19	5650	22.98	8150
30.21	700	27.56	3200	25.15	5700	22.94	8200
30.15	750	27.51	3250	25.10	5750	22.90	8250
30.10	800	27.46	3300	25.05	5800	22.86	8300
30.04	850	27.41	3350	25.01	5850	22.82	8350
29.99	900	27.36	3400	24.96	5900	22.77	8400
29.93	950	27.31	3450	24.92	5950	22.73	8450
29.88	1000	27.26	3500	24.87	6000	22.69	8500
29.82	1050	27.21	3550	24.82	6050	22.65	8550
29.77	1100	27.16	3600	24.78	6100	22.61	8600
29.71	1150	27.11	3650	24.73	6150	22.57	8650
29.66	1200	27.06	3700	24.69	6200	22.52	8700
29.61	1250	27.01	3750	24.64	6250	22.48	8750
29.55	1300	26.96	3800	24.60	6300	22.44	8800
29.50	1350	26.91	3850	24.55	6350	22.40	8850
29.44	1400	26.86	3900	24.51	6400	22.36	8900
29.39	1450	26.81	3950	24.46	6450	22.32	8950
29.34	1500	26.76	4000	24.42	6500	22.28	9000
29.28	1550	26.72	4050	24.37	6550	22.24	9050
29.23	1600	26.67	4100	24.33	6600	22.20	9100
29.17	1650	26.62	4150	24.28	6650	22.16	9150
29.12	1700	25.57	4200	24.24	6700	22.11	9200
29.07	1750	26.52	4250	24.20	6750	22.07	9250
29.01	1800	26.47	4300	24.15	6800	22.03	9300
28.96	1850	26.42	4350	24.11	6850	21.99	9350
28.91	1900	26.37	4400	24.06	6900	21.95	9400
28.86	1950	26.33	4450	24.02	6950	21.91	9450
28.80	2000	26.28	4500	23.97	7000	21.87	9500
28.75	2050	26.23	4550	23.93	7050	21.83	9550
28.70	2100	26.18	4600	23.89	7100	21.79	9600
28.64	2150	26.13	4650	23.84	7150	21.75	9650
28.59	2200	26.09	4700	23.80	7200	21.71	9700
28.54	2250	26.04	4750	23.76	7250	21.67	9750
28.49	2300	25.99	4800	23.71	7300	21.63	9800
28.43	2350	25.94	4850	23.67	7350	21.59	9850
28.38	2400	25.89	4900	23.62	7400	21.55	9900
28.33	2450	25.85	4950	23.58	7450	21.51	9950

Barometric Indications.—The barometer not only indicates an increased or decreased pressure on the occluded gases in the pores of the coal, or determines the height of mountains or depth of shafts, but also forecasts the weather.

A rapid fall or a rapid rise of the barometer indicates that a strong wind is about to blow and that this wind will bring with it a change in the weather. What the nature of the change will be will depend upon the direction from which the wind blows.

If an observer stands facing the wind the locality of low barometric pressure will be at his right and that of high barometric pressure at his left. With low pressure in the west and high pressure in the east, the winds will be from the south; but with low pressure in the east and high pressure in the west, the wind will be from the north.

A slow but steady rise indicates fair weather.

A slow but steady fall indicates unsettled or wet weather.

A rapid rise indicates clear weather with high winds.

A very slow fall from a high point indicates wet and unpleasant weather without much wind.

A sudden fall indicates a sudden shower or high winds or both.

When a barometer falls considerably without any precise change of weather it may be certain that a storm is raging at a distance.

A stationary barometer indicates a continuance of existing conditions, but a slight tap on the barometer face will likely move the hand a trifle, indicating whether the tendency is to rise or fall.

The principal maximum barometer pressure occurs before noon and the principal minimum after noon.

Example.—If the barometer reading is 30 inches, (*a*) what is the pressure per square inch on the face and

sides of a chamber in a mine? (*b*) If the reading is 28 inches, what is the pressure?

Ans. (*a*) 14.7 lbs.
(*b*) 13.72 lbs.

By the above example it is readily seen that as the pressure per square inch is less with a barometer of 28 inches than with a barometer of 30 inches, a larger volume of gas will escape from fissures and pores of the coal, thus rendering the mine atmosphere more dangerous than if the barometer stood at 30 inches.

54. Effect of Temperature and Pressure on Volume of Gases.—CHARLES' LAW.—It has been found by experiment that under constant pressure *all gases expand or contract equally for equal changes of temperature.* More explicitly, a gas expands or contracts 1/491 of its volume at 32° F., for every degree through which it is heated or cooled. This means that 491 cubic feet of gas at 32° F. becomes 492 cubic feet at 33° F., 490 at 31° F.

BOYLE'S LAW.—It has been found by experiment that under constant temperature *the volume of a gas is inversely proportional to the pressure.* This means that doubling the pressure halves the volume, and vice versa. If a gas is under a certain pressure and the pressure is diminished to $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc., of its original pressure, the gas will increase in volume 2, 4, 8, etc., times. Its tension increasing the volume will decrease at the same rate.

EXAMPLE.—If 6 cu.ft. of air be under a pressure of 10 lbs. (*a*) what will be the volume when the pressure is 20 lbs.? (*b*) when the pressure is 5 lbs., temperature remaining the same?

$$(a)\ \text{vol.} = \frac{6\times10}{20} = 3 \text{ cu.ft.}$$

$$(b)\ \text{vol.} = \frac{6\times10}{5} = 12 \text{ cu.ft.}$$

It should be remembered that, *when the temperature remains the same, the volume of a given quantity of gas varies inversely as the pressure.*

By means of the following formula the increased or decreased volume of a gas, due to an increase or decrease in the temperature, can be found, pressure remaining constant.

Let v = volume of gas before heating;
v' = volume of gas after heating;
t = temperature corresponding to volume v;
t' = temperature corresponding to volume v'.

Thus,

$$v' = v\frac{(459+t')}{(459+t)}.$$

EXAMPLE.—If 10 cubic feet of air at a temperature of 40° is heated under constant pressure until the temperature reaches 150°, what is the new volume?

$$v' = v\,\frac{459+150}{459+40} = 10\times\frac{(609)}{(499)} = 12.20 \text{ cu.ft.}$$

55. Absolute Zero.—The atoms and molecules of all bodies are in a constant state of vibration. An increase of heat will increase this vibratory movement and a decrease of heat will have the opposite effect. This vibratory movement will continue, however, until a temperature 459° F. below zero is reached, at which point the movement will cease. 459° F. is called absolute zero.

No one has ever succeeded in depriving a body of all its heat or cooling it to absolute zero, though some experiments have come within 10° of it; nevertheless, it has a meaning and is used in many formulas.

EXAMPLE.—If 10,000 cu.ft. of air enters a mine at a

temperature of 30° F., what volume will leave the mine if the temperature in the return airway is 70° F.?

Ans. 10,818 cu.ft. nearly.

ABSOLUTE TEMPERATURE.—If the absolute temperature of a gas is known the ordinary temperature may be found by subtracting 459° from the absolute temperature.

EXAMPLE.—If the absolute temperature of a quantity of air is 500° F., the ordinary temperature is $500° - 459° = 41°$ F.

The pressure, volume, temperature or weight of air can be found by the following formulas, in which

P = pressure per square inch;
V = volume of air in cubic feet;
T = absolute temperature;
W = weight of the air;

$$P = \frac{.37052WT}{V};$$

$$V = \frac{.37052WT}{P};$$

$$T = \frac{PV}{.37052W};$$

$$W = \frac{PV}{.37052T}.$$

EXAMPLE.—If 20 cubic feet of air weighs 2 pounds and the temperature is 60° F., what is the pressure or tension in pounds per square inch?

Solution.—$P = \frac{.37052WT}{V} = \frac{.37052 \times 2 \times 519}{20} = 19.23$ lbs. per sq.in. nearly. *Ans.*

EXAMPLE.—The temperature of a certain quantity of air is 60° F. Its weight is 2 lbs. and the pressure per square inch is 19.23 lbs. What is the volume?

Solution.—$V = \frac{.37052WT}{P} = \frac{.37052 \times 2 \times 519}{19.23} = 20$ cu.ft. *Ans.*

EXAMPLE.—If 20 cubic feet of air have a (pressure) tension of 19.23 lbs. per square inch and weighs 2 lbs., what is the temperature?

Solution.

$$T = \frac{PV}{.37052W} = \frac{19.23 \times 20}{.37052 \times 2} = 519. \quad 519 - 459 = 60° \text{ F.} \quad \textit{Ans.}$$

EXAMPLE.—If 20 cubic feet of air have a tension of 19.23 lbs. and a temperature of 60° F., what is the weight?

Solution.—$W = \frac{PV}{.37052T} = \frac{19.23 \times 20}{.37052 \times 519} = 2$ lbs. *Ans.*

If a certain quantity of gas is heated through any number of degrees and the volume remains the same the tension or pressure will increase. For example, if a volume of gas is confined in a cylinder and if the gas is heated, its tendency to expand is prevented by the sides of the cylinder, consequently, the tension or pressure of the gas is increased. It will be found that for every increase of temperature of 1° F. there will be an increase of $\frac{1}{491}$ of the original tension at 32° F.

If the gas is free to expand adding heat will increase the volume and the tension will remain constant.

EXAMPLE.—If a quantity of gas is heated from 30° F. to 70° F., the volume remaining constant (that is the volume enclosed so it cannot expand), what is the resulting tension if the original tension was 14.7 lbs. per square inch?

p = original tension;
t = original temperature;
t' = any temperature;
p' = corresponding tension.

$$p' = p\,\frac{(459+t')}{(459+t)};$$

$$p' = 14.7\,\frac{(459+70)}{(459+30)} = 14.7\frac{(529)}{(489)} = 15.9, \text{ pressure per sq.in.}$$

EXAMPLE.—If a quantity of gas is heated under constant volume from 30° F. to 100° F., what is the resultant tension, the original tension being equal to one atmosphere?

The term "a pressure of one atmosphere" is sometimes used as a unit of pressure; it means 14.7 lbs. Thus, two atmospheres mean a pressure of 29.4 lbs. per sq.in.

56. Calculation of the Weight of a Gas at Different Temperatures and Pressures.—The weight per cubic foot of any gas at different temperatures and pressures can be found by the following formula:

Let W = weight in pounds;
V = volume in cubic feet;
B = barometric pressure;
S = specific gravity;
T = absolute temperature.

EXAMPLE.—If 250 persons are employed in a mine and each person is allowed 200 cubic feet of air per minute, what is the weight in tons of the air passing through the mine in 10 hours, the temperature being 60° F. and the barometer 30 inches?

Solution.—$250\times200\times60\times10 = 30{,}000{,}000$ cu.ft.

$$W=\frac{1.3253\times B}{T}=W\frac{1.3253\times 30}{459+60}=.0766 \text{ weight per cu.ft.}$$

$$\frac{.0766\times 30{,}000{,}000}{2000}=1149 \text{ tons.} \quad \textit{Ans.}$$

Example.—What is the weight of 100 cubic feet of carbon dioxide gas at a pressure of 30 inches and a temperature of 30° F.?

Note.—The constant, 1.3253, is the weight in pounds of one cubic foot of air at 1° absolute temperature (F.) and 1 inch barometer.

Solution.—$W=\dfrac{1.3253BVS}{T}$.

$$W=\frac{1.3253\times 30\times 100\times 1.527}{459+30}=12.4 \text{ lbs.} \quad \textit{Ans.}$$

QUESTIONS

1. What do we mean when we say a barometer is compensated?
2. What is the meaning of the words "stormy," "change," "fair," etc., upon the dial of an aneroid barometer?
3. Which will denote a change in pressure more quickly, the aneroid or mercurial barometer?
4. What is the weight of a cubic inch of mercury?
5. Why is mercury used in a barometer instead of some other liquid?
6. What is the average pressure of the atmosphere per square inch at sea level?
7. If 2 cubic feet of air are under a pressure of 50 lbs. per square inch, (*a*) what will be the pressure when the volume is increased to 5 cubic feet? (*b*) to 3 cubic feet?

8. If 20 cubic feet of air have a tension of 6 lbs. per square inch, (*a*) what is the volume when the tension is 5 lbs.? (*b*) 10 lbs.? (*c*) 15 lbs.?

9. The weight of 1 cubic foot of air at a temperature of 60° F. and under a pressure of 1 atmosphere (14.7 lbs. per square inch) is .0766 lb., what would be the weight per cubic foot if the volume be compressed until the tension is 6 atmospheres, temperature remaining the same?

10. If in the last example the air had expanded until the tension was 10 lbs. per square inch, what would have been its weight per cubic foot?

11. If 10 cubic feet of air at a temperature of 60° F. and a pressure of 1 atmosphere are compressed to 4 cu.ft. (temperature remaining the same) what is the weight of a cubic foot of the compressed air?

12. When 5 cubic feet of air at a temperature of 40° F. are heated under constant pressure up to 150° F., what is the new volume?

13. What is the weight of 100 cubic feet of air at a temperature of 60°, barometer 30 inches?

14. What is the weight of 100 cubic feet of marsh gas (conditions same as question 13)?

15. What is the weight of (*a*) 100 cubic feet of carbon dioxide, (*b*) 100 cubic feet of carbon monoxide (temperature and pressure same as in question 13)?

16. Which is the more dense, (*a*) air or marsh gas, (*b*) air or carbon dioxide?

17. There are two shafts connected under ground and so located that the barometer reading at the top of the first shaft is 29 ins. and at the top of the second shaft 30 ins.; the temperature in the first shaft is 60° and in the second 100°, in what direction will the air move (natural ventilation)?

18. If water were used in the construction of a barom-

eter, what would be the height of a water barometer when the mercurial barometer stands at 30 ins.? at 25 ins.?

19. Explain the principle involved in using the barometer to measure elevations.

20. Why do we not feel the pressure of the atmosphere?

CHAPTER IX

GASES

57. Acetylene Gas.—Acetylene burns in the air with a smoky, luminous flame, but when air is mixed with the gas as it issues from a small opening such as the jet of a miner's lamp, the mixture burns with a brilliant white flame which does not smoke, in view of which the lamp is now used quite extensively in the mines. The flame is much smaller than an ordinary gas flame of the same lighting power.

Acetylene is generated by putting calcium carbide into a flask and allowing water to drop slowly upon the carbide. A pound of calcium carbide yields about 5 cubic feet of acetylene gas. The formula for acetylene is C_2H_2.

Acetylene is slightly poisonous, though very much less so than carbon monoxide. Investigations made by the Bureau of Mines with acetylene generated from carbide such as is used in a miner's lamp, indicate that there is little if any chance of men being poisoned because of the use of acetylene in mines. Acetylene, of course, is suffocating, as are carbon dioxide, nitrogen and hydrogen. Its ignition temperature is about 970° F.

Calcium carbide is made by heating a mixture of lime and coke in an electric furnace. It is a hard, brittle solid; its specific gravity is 2.2. Owing to its action with water, it should be packed in air-tight cans. Fig. 11 shows the style lamp used in the mines for lighting purposes.

The acetylene lamp will burn in air that contains only

10 to 11 per cent of oxygen, a proportion which is much too low to support the flame of an ordinary oil lamp. For this reason objection has been made to the use of acetylene lamps in mines, because they may not warn the miners that the atmosphere is so low in oxygen as to cause them immediate harm. If a man exerts himself in such atmosphere his labored breathing warns him that the air is not fit to breathe. The best authorities agree that a man will

FIG. 11.

live without serious inconvenience in an atmosphere where the oxygen is reduced to 10 per cent. Deficiency of oxygen becomes a real danger when it is as low as 7 or 8 per cent. The acetylene flame is extinguished before the danger point is reached and the suggestion that it does not give adequate warning by extinction in an atmosphere low in oxygen has been disproved not only scientifically but practically. However, in the absence of a mine fire or other unusual condition, the oxygen content should not be permitted to fall below 20 per cent.

PERCENTAGE TO WHICH OXYGEN MUST BE REDUCED TO EXTINGUISH VARIOUS FLAMES

Combustible.	Percentage of Oxygen.
Candle	16 to 17
Benzine	16 to 17
Hydrogen	7 to 8
Acetylene	10 to 11
Petroleum	16 to 17

58. Safety Lamps.—It frequently happens that an explosive mixture of gases accumulates in coal mines; an ordinary lamp brought in contact with this mixture would cause an explosion. To prevent this and still make it possible to use a light, Sir Humphry Davy devised a form of lamp (Fig. 12) in which the flame is entirely surrounded with wire gauze. Whenever the lamp is brought into an inflammable mixture of gases some of the mixed gas will enter the lamp and burn there, but the heat is absorbed by the gauze to such an extent that the gas outside the lamp does not receive heat enough to ignite until the gauze becomes so heated that it cannot take any more heat from the burning gas; the flame will then pass through the gauze and light the gas in the surrounding atmosphere.

FIG. 12.

The standard adopted as a limit of safety was iron wire gauze with 784 meshes per square inch, the wires being about $\frac{1}{60}$ inch in thickness. In a dangerous atmosphere the entire space within the gauze becomes occupied with flame; under such condition the lamp should be removed

carefully from the gaseous mixture, making no quick movements while doing so.

Modifications of the Davy lamp have come into use, chiefly with a view to surrounding the flame with glass so as to increase the effective radiation of light; but in each case ingress and egress of air are effected through one or more thicknesses of wire gauze.

The lamps most commonly used are the Davy, Clanny, Koehler and Wolf. The features most desired in a safety lamp are (1) safety in strong currents; (2) maximum illuminating power; (3) security of lock; (4) so constructed that it can be relighted without opening the lamp; (5) simplicity of construction.

59. Occlusion of Gases.—A gas is occluded when it is absorbed and pent up in the pores of any substance. Hydrogen is absorbed freely by several metals, especially platinum and palladium. Gases exist in varying quantities in coal seams; those most commonly occluded in the coal are marsh gas or methane, carbon dioxide, nitrogen, oxygen and ethane. The pressure of the occluded gases is sometimes as high as 12 to 15 atmospheres.

In newly-exposed coal faces the gas can be heard and felt exuding from the pores. Many cases are recorded where the flow of gas from coal seams was so strong that a formerly reasonably safe atmosphere became in a short time explosive.

The writer has many times heard it said that in some mines gas exudes with such force from the coal seams that it prevents the movement of the air. This is due, not to the force with which the gas is emitted, but to the volume of gas given off.

To remove a large body of firedamp it would require a pressure much greater than the average mine fan now in operation can produce.

60. Properties.—All gases conform and behave uniformly with changes of pressure and with changes of temperature. Thus if the pressure on a certain volume of marsh gas be doubled the volume will be reduced one-half, and if the pressure on a volume of carbon dioxide be doubled the volume will also be reduced one-half, temperature remaining the same. Also if the temperature of several gases be increased one degree the amount of increase in volume will be the same in all, pressure remaining the same.

There is an equal number of molecules in equal volumes of all gases at the same temperature and pressure. Therefore, since one molecule of oxygen weighs 16 times more than one molecule of hydrogen, 100 molecules of oxygen will weigh 16 times more than 100 molecules of hydrogen.

61. Physical Properties of Air.—Air when pure is colorless, tasteless, odorless and transparent. It can be liquefied by pressure at a very low temperature. It is 14.4 times as heavy as hydrogen.

62. Chemical Properties of Air.—Air can not be truly represented by a formula; the elements of which it is composed are not fixed, but vary between small limits; however, for convenience air is often represented by the formula ON_4. The oxygen and nitrogen of which air is chiefly composed are held together loosely and can be separated with very little energy. The oxygen of the atmosphere supports combustion, the energy of which is checked by the diluting nitrogen. When air containing carbon dioxide is passed through lime-water the carbon dioxide renders the clear liquid milky in appearance.

63. Carbon Monoxide.—This gas is sometimes called white damp (CO). When burned, a blue flame, such as is produced by the burning of anthracite coal, can be seen. Carbon monoxide is produced when carbon is burned in a limited supply of air.

64. Properties.—Carbon monoxide is a very poisonous gas; it is doubly dangerous because its lack of odor prevents its detection.

The gas is a little lighter than air, its density being 14. It does not support combustion, but is combustible. It burns with a pale blue flame and yields carbon dioxide (CO_2) as the sole product of its combustion. One half per cent of it in the air is fatal to life.

The best antidote is the free inhalation of pure oxygen.

When a lighted lamp is placed in an atmosphere containing this gas the flame brightens and lengthens into a more or less slim taper with a bluish tip. This feature is, however, of no use as a distinguishing property, and should be disregarded by the miner.

65. How Produced.—Carbon monoxide is a product of the incomplete combustion of carbonaceous fuel when the supply of air is limited. Mine fires and explosions of powder and firedamp are the principal sources of this gas in mines.

66. Explosive Properties.—Carbon monoxide mixed with air is explosive, but explosions of mixtures of carbon monoxide and air in mines are very rare. However, if an atmosphere contains 15.5 per cent of carbon monoxide, it will explode, but such a large percentage of carbon monoxide is seldom found in the gases from a mine fire. A mixture of carbon monoxide and air containing too little carbon monoxide to be explosive may become explosive by the addition of enough marsh gas, even if the proportion of marsh gas in the mixture be below the explosive limit of marsh gas and air.

67. Carbon Dioxide.—CO_2, commonly called "black damp," is a colorless gas and is about one and one-half times heavier than air, its density being 22.

On account of its weight it can be displaced and poured from one vessel to another.

This gas diffuses very slowly on account of its high density, therefore it often accumulates in low places in mines. The gas is soluble in water volume for volume at ordinary temperatures and pressures. It is not as dangerous as carbon monoxide. It can be detected by an ordinary lamp; the light becomes dim and appears to pull away from the wick.

If air containing carbon dioxide is passed through lime-water the liquid becomes milky. The exhausts from gasoline engines used in mines are sometimes so arranged that they exhaust through lime-water. The carbon dioxide unites with the lime in the water and is thereby prevented from being discharged into the atmosphere.

If a known volume of dry air is forced through a known weight of lime-water the increase in weight of the water will be the weight of carbon dioxide in the volume of air used.

68. How Produced.—Carbon dioxide is formed when carbon or any substance containing carbon is burned in a plentiful supply of air; thus mine fires, explosions of gas, burning of lamps and explosions of powder are the principal producers of carbon dioxide by combustion in mines. It is also produced when vegetable and animal matter decays and by the breathing of men and animals. As the gas is very soluble in water it is largely carried into a mine in this manner and when the water evaporates the gas escapes. The gas is incombustible and will not support combustion.

When two volumes of oxygen unite with one volume of carbon, forming the compound CO_2, combustion or oxidation is complete; in other words, the carbon is satisfied with oxygen; the oxygen, however, is not satisfied with carbon, and if carbon be met with in a free state the oxygen will take up another atom of the element, thus

$$CO_2 + C = 2CO.$$

69. Effect of Blackdamp on Atmospheres Containing Firedamp.—It has been found by experiment that atmospheres containing only 13 per cent of oxygen may be explosive when enough methane is also present. Consequently the atmosphere in one part of the mine may contain blackdamp enough to extinguish an oil flame and be non-explosive, but farther on in the mine where more methane is present an electric spark or a flame may cause an explosion.

70. Marsh Gas.—Marsh gas (CH_4) is a colorless, odorless, tasteless gas; it is slightly soluble in water. It is one of the lightest known substances, its density being 8.

It is produced by the decay of vegetable matter confined under water in the absence of air. It is found to a greater or less extent in all coal seams, and when mixed with air in the following proportions forms firedamp.

NOTE.—Marsh gas is also known as methane or light carbureted hydrogen; either term may be used when referring to the gas.

Lowest explosive limit:

$$\begin{array}{lr} \text{Volume of marsh gas} & = 1 \\ \text{Volume of air} & = 5.5 \\ \hline & 6.5 \end{array}$$

Percentage of gas in mixture $\frac{1}{6.5} \times 100 = 15.38$ per cent.

Greatest explosive force:

$$\begin{array}{lr} \text{Volume of marsh gas} & = 1 \\ \text{Volume of air} & = 9.5 \\ \hline & 10.5 \end{array}$$

Percentage of gas in mixture $\frac{1}{10.5} \times 100 = 9.52$ per cent.

Highest explosive limit:

$$\begin{array}{lr} \text{Volume of marsh gas} = & 1 \\ \text{Volume of air} \quad = & 13 \\ \hline & 14 \end{array}$$

Percentage of gas in mixture $\frac{1}{14} \times 100 = 7.14$ per cent.

On account of its low density marsh gas diffuses very rapidly with air, forming firedamp. This mixture, owing to its lightness, ascends and lodges along the roof of the mine.

Some idea of the enormous quantity of marsh gas that may be carried from a mine by the ventilating current is shown by the following statement: In the main return airway of a certain mine 150,000 cu.ft. of air is passing per minute; this air contains 1 per cent of marsh gas, hence the total amount of gas expelled from the mine in 24 hours is $150{,}000 \times 60 \times 24 \times .01 = 2{,}160{,}000$ cu.ft.

An explosive mixture of marsh gas (or methane) and air ignites if heated to a temperature of about 1212° F. If the flame be cooled below this temperature it goes out.

Sulphureted hydrogen when mixed with the quantity of air necessary for complete combustion will ignite at a temperature of about 600° Fahrenheit, while ethane, ethylene and carbon monoxide will, under the same conditions, ignite at about 1300° Fahrenheit.

The relative humidity of the mine air will affect the explosive limits of marsh gas and air, thus a percentage

of marsh gas that would just make under-saturated air explosive would be totally inexplosive in air saturated with watery vapor. It has also been found by experiment that a mixture of marsh gas and air that is outside the explosive limits is rendered explosive by an increase of pressure. A heavy blast in a mine might create sufficient pressure to render an inexplosive mixture explosive.

71. Detection of Firedamp.—Firedamp is detected by means of the safety-lamp. The lamp should be raised cautiously in a vertical position to the place where gas is suspected. Some prefer testing with the ordinary working flame, while others prefer a much smaller light. If gas be present it will flame inside the gauze. If it is desired to test for a small percentage of gas in the atmosphere the wick must be pulled down until a very small light appears above the burner. In this case the presence of gas is manifested by a non-luminous cap above the flame.

When a Davy lamp burning sperm or lard oil is employed the height of the cap produced in any percentage of gas will vary slightly, depending on the original flame used. The results obtained will be more uniform if the wick is drawn down until a very small light remains. The percentage of gas in the atmosphere can then be calculated as follows:

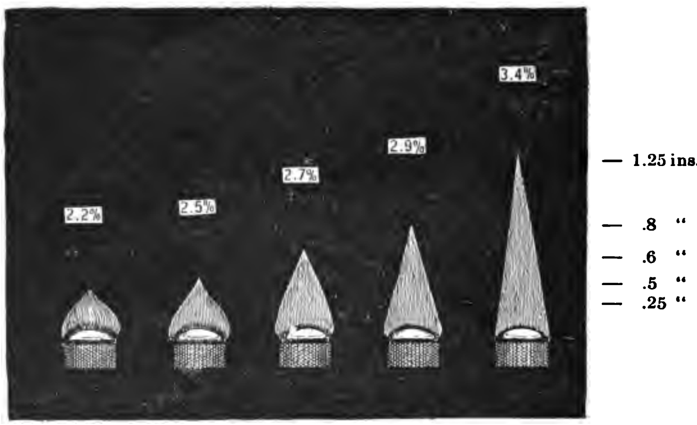
P = percentage of gas in the air;
h = height of gas cap in inches;
$P = \sqrt[3]{36 \times h}$.

Thus, if the lamp indicated $\frac{1}{2}$ inch cap the percentage of gas present is

$$P = \sqrt[3]{36 \times .5} = 2.6 \text{ per cent of gas.}$$

NOTE.—By experiments conducted by Mr. Beard he discovered that in an unbonneted Davy lamp the height of the flame cap was $\frac{1}{36}$ of the cube of the percentage of gas producing the cap.

72. Ethane.—Ethane (C_2H_6) is a member of the marsh-gas series. It is a colorless, odorless and tasteless gas



with properties very similar to those of marsh gas; it is rarely found in mines.

It is produced by dry decomposition of vegetable matter, and is explosive when mixed with air.

73. Ethylene.—Ethylene (C_2H_4), or olefiant gas, is formed by the destructive distillation of wood and coal. It is a colorless gas and has a pleasant odor. It burns with a bright yellow flame and is one of the illuminating constituents of coal gas.

74. Sulphureted Hydrogen.—Sulphureted hydrogen (H_2S) is seldom found in mines in large quantities. It is a colorless gas and has an odor of rotten eggs. It is

poisonous. When breathed in small quantities it produces headache and larger quantities renders one unconscious. It explodes violently when mixed with air to about seven times its volume. The gas is soluble in water—one volume of water dissolving about three volumes of the gas at ordinary temperature and pressure.

A familiar example of the action of this gas is seen in its effect upon silver, which becomes covered by a bluish-black deposit after being exposed for a short time to air containing the gas.

The gas occurs in the waters of sulphur springs; it is often found in the air in sewers and is produced by the decay of organic matter containing sulphur.

75. Hydrogen.—Hydrogen has no taste or color. The pure gas has no odor, though hydrogen as ordinarily prepared has a disagreeable odor, due mainly to impurities in the metals used. Hydrogen is the lightest known substance. Volume for volume, air is about 14.4 times and oxygen 16 times, and water 11,000 times heavier than hydrogen.

76. Combustion of Hydrogen.—When hydrogen is heated to the temperature of about 932° F. in the presence of free oxygen, the two elements enter into chemical union, forming water (H_2O). Whatever the condition under which hydrogen is burned in oxygen or in air, the sole product is water.

$$2H_2+O_2=2H_2O.$$

77. Water Gas.—Water gas is prepared by bringing superheated steam into contact with incandescent coal or coke. The steam is decomposed, and hydrogen and carbon monoxide are produced.

$$C+H_2O=CO+H_2.$$

These products are combustible, yield a non-luminous

flame and intense heat. An anthracite mine fire furnishes a good condition for the production of these gases; when water or steam comes in contact with the fire, of course, the supply of atmospheric oxygen in the fire zone would, necessarily, have to be low to prevent the combustion of the mixed product.

Gas samples obtained by the writer in an anthracite mine from behind a stopping that sealed a mine fire, showed by analysis 2.6 per cent of carbon monoxide and 3.14 per cent of hydrogen. The sample, however, did not truly represent the atmospheric condition at the fire, because it was taken several hundred feet away from the fire area, and the fire gases were diluted with air that leaked through other walls surrounding the fire.

78. Effect of Carbon Dioxide on Respiration.—The quantity of carbon dioxide in air varies from about 0.03 per cent in fresh country air to about 0.1 to 0.2 per cent in crowded rooms or theaters. In mines well ventilated under ordinary working condition, the quantity of carbon dioxide found will rarely exceed 0.4 to 0.5 per cent; much larger percentages have been found, however, but the conditions under which they were found were unusual.

It has been shown by investigation that carbon dioxide to the extent of 1 to 1.75 per cent is not injurious; the depth and frequency of breathing is increased about one-sixth, which is not noticeable.

Air containing about 3 per cent carbon dioxide has a noticeable effect and would probably be harmful if breathed for any considerable time.

Prof. Haldane states: "In an atmosphere containing about 5 to 6 per cent carbon dioxide there is a marked panting, accompanied by a rise of pulse; at 10 per cent there is violent panting, and flushing of the face; headache is also produced, especially on a return to fresh air; above

10 per cent it begins to have a narcotic effect and at about 25 per cent death may occur after several hours, but as much as 50 per cent can be breathed for some time without fatal effects." It should be remembered, however, that the above figures apply to air from which no oxygen is displaced by the carbon dioxide.

79. Preparation of Carbon Dioxide.—This gas is usually prepared by pouring hydrochloric acid upon calcium carbonate.

80. Effect of Carbon Monoxide.—In discussing this subject Prof. Haldane states that 0.05 per cent in pure air is just sufficient to produce in time very slight symptoms of poisoning in man; that 0.10 per cent may cause a headache in forty or fifty minutes or a slight palpitation of the heart in less time; and that 0.20 per cent is very dangerous to man.

81. Preparation of Carbon Monoxide.—Carbon monoxide is usually prepared by gently heating a mixture of oxalic acid and sulphuric acid in a flask, and collecting the gaseous product over water.

82. Effect of a Reduced Oxygen Content.—Ordinarily, pure air contains 20.93 per cent oxygen; in coal mines, however, the composition of the atmosphere changes; oxygen is absorbed by the coal and the oxidation of coal to carbon dioxide is constantly going on; for this reason, the composition of mine air is never chemically pure.

Out of forty samples of air collected and analyzed by the writer, only one showed an oxygen content below 18 per cent; the remaining thirty-nine samples contained from 19.5 to 20.5 per cent oxygen. This slight reduction in oxygen will have no harmful effect.

The belief is quite general that air in which a candle will not burn is not fit to breathe, and many who have been in such an atmosphere for a short time imagine they have had a narrow escape. The margin of safety is, however, much

greater than they suppose. A candle will be extinguished in an oxygen content of from 16 to 17 per cent, while a person not exerting himself will fail to notice any unusual effects until the oxygen is reduced to 11 or 12 per cent. However, if an atmosphere be so low in oxygen that an oil-fed flame will not burn, it is time to retreat to a place where purer air may be had.

83. Oxygen Content at Different Altitudes.—At an altitude of about 5500 ft., the partial pressure of oxygen is only 17 per cent of an atmosphere. Dr. Leonard Hill states: "Men work hard and live healthy lives in the high altitude regions of the earth, where the partial oxygen pressure is only 16 per cent of an atmosphere. It is found that patients suffering from lung trouble receive much benefit by breathing an artificial atmosphere containing only 17 per cent of oxygen; the respiratory movement is stimulated, the chest expansion is increased and causes a gain in the lung capacity and the weight of the body."

In the case of respiration, it is the weight of oxygen in a given volume that is necessary, while in the case of combustion, it is the percentage amount of oxygen that must be considered.

A cubic foot of air at sea level containing 17 per cent oxygen contains as much oxygen by weight as a cubic foot with 21 per cent oxygen at an altitude of 5500 feet. An oil-fed flame will be affected in the former, but will burn freely in the latter mixture.

84. Effect of a Reduced Oxygen Content on Inflammability of Methane and Air.—A mixture containing 9.45 per cent methane and 90.53 per cent of air contains enough oxygen for complete combustion of the methane to carbon dioxide and water vapor. If less oxygen or more methane be present, combustion will be incomplete and carbon monoxide and hydrogen will be produced.

In discussing the possibility of a dust explosion in an atmosphere with a reduced oxygen content, Dr. J. Harger states: "There is little doubt that all the great mine explosions have been caused by the enforcement of a high degree of chemical purity of air. In the old days, when ventilation was bad, there were no great dust explosions. With the more dangerous kinds of dust a reduction to 20 per cent of oxygen with .5 per cent carbon dioxide present, would not be sufficient precaution; the reduction must be to 19 per cent oxygen, or less, with .75 to 1 per cent of carbon dioxide present. A reduction of oxygen by the small amounts mentioned above would not entirely remove the possibility of fire damp ignition, but it would very greatly diminish the chance of accident, and by further reduction to the limits found experimentally, i.e., 17.5 per cent oxygen, the risk of explosions could be entirely eliminated."

Arguments put forth in support of the above statement are based on the fact that in ordinary air containing methane, from 5.5 per cent, the low explosive limit, to 15 per cent, the high explosive limit, the mixtures will explode, while with air containing less oxygen the limits are drawn together until the oxygen content is reduced to 17.5 per cent, when they finally coincide at 8.75 per cent, the chance of getting such a mixture in a mine being quite remote.

The United States Bureau of Mines discovered that with 17 per cent of oxygen the low explosive limit was raised to 5.7 per cent, but even with 13 per cent of oxygen the mixture was explosive with any methane content between 6.6 per cent as the low limit and 6.8 per cent as the high limit, and that a large amount of carbon dioxide was necessary to affect appreciably the limits. With an oxygen content of 20 per cent and the replacement of part of the nitrogen by a carbon dioxide content of 62 per cent the low limit was raised to 8.8 per cent methane.

Table J

SAMPLES OF MINE AIR EXAMINED AND RESULTS OF THE EXAMINATION

State.	County.	Kind of Coal.	Volume of Air Current, Cu.ft. per Min.	CO_2 in Sample, per Cent.	CH_4 in Sample, per Cent.
Pennsylvania	Luzerne	Anthracite	18,100	0.07	1.34
"	"	"	18,100	.07	1.34
"	"	"	25,760	.07	1.16
"	"	"	178,560	.09	.76
"	"	"	178,560	.09	.78
"	"	"	90,000	.06	1.01
"	"	"	90,000	.05	1.04
"	"	"	140,344	.08	.35
"	"	"	140,344	.08	.37
"	"	"	(a)	.04	.02
"	"	"	(a)	.05	.04
"	"	"	(a)	.05	2.34
"	"	"	(a)	.07	2.37
"	"	"	44,200	.04	1.57
"	"	"	44,200	.02	1.60
"	Lackawanna	"	28,764	.33	.52
"	"	"	28,764	.30	.50
"	"	"	21,000	.28	.76
"	"	"	21,000	.27	.75
"	Luzerne	"	17,136	.13	1.27
"	"	"	17,136	.10	1.27
"	"	"	60,060	.16	2.29
"	"	"	23,760	.14	2.20
"	"	"	23,760	.13	2.19
"	"	"	13,600	.17	3.06
"	"	"	13,600	.16	3.05
"	Williamson	Bituminous	36,190	.24	.14
"	"	"	41,580	.35	.21
"	"	"	54,225	.05	.09
"	"	"	16,240	.37	.21
"	"	"	13,650	.44	.19
"	"	"	23,870	.05	.00
"	Jackson	"	30,800	.05	.02

(a) Still air.

TABLE J—*Continued*

State.	County.	Kind of Coal.	Volume of Air Current, Cu.ft. per Min.	CO_2 in Sample per Cent.	CH_4 in Sample. per Cent
Pennsylvania	Jackson	Bituminous	55,300	.11	.04
"	"	"	20,844	.31	.00
"	Franklin	"	90,396	.05	.03
"	"	"	64,288	.10	.24
"	"	"	6,000	.10	.35
Colorado	Fremont	"	(*a*)	.19	.34
"	"	"	(*a*)	.29	.41
"	"	"	27,090	.05	.21
West Virginia	"	"	14,000	.05	.88

(*a*) Still air.

QUESTIONS

1. What is calcium carbide?
2. How is it made and for what is it used?
3. How should it be stored?
4. What is acetylene gas?
5. Describe the acetylene flame.
6. What precautions should be observed in using acetylene gas as an illuminant in the mine?
7. What is the formula for acetylene gas?
8. What is the specific gravity of acetylene gas?
9. Does the flame from an acetylene lamp give off smoke?
10. What are the dangers to be met with in the use of acetylene lamps in the mine?
11. What is meant by the term "occluded gases"?
12. What are the physical properties of air?
13. What is black damp?
14. How is carbon monoxide produced?
15. How may carbon monoxide be changed to CO_2?

16. How is carbon dioxide produced and what is its density?

17. Where is carbon dioxide usually found? Why?

18. How is marsh gas produced? (*a*) What is its density? (*b*) What is its chemical formula?

19. What is firedamp?

20. What per cent of gas is in the mine atmosphere when it is (*a*) at its lowest explosive limit? (*b*) Highest explosive limit? (*c*) When the mixture is such that the explosive force is greatest?

21. What effect has the relative humidity of the atmosphere on the explosive limits of firedamp?

22. How is firedamp detected?

23. If a cap of one inch appeared on your safety lamp, what is the per cent of gas in the atmosphere?

24. What is the formula and density of ethane? How is it produced?

25. What is the density of sulphureted hydrogen and how is it produced?

26. If CO gas is passing over a fire how may it be reduced to CO_2?

27. An ordinary wick-fed flame goes out when the proportion of oxygen in mine air is reduced to about 17 per cent. Will an acetylene flame burn in this percentage of oxygen?

28. What is changed when a gas is compressed? the size of the molecules or the distance between them?

29. How much must the volume of air in a pneumatic drilling hammer be compressed to drive it at a pressure of 45 lbs. per square inch?

30. How deep must water be in a vessel so that its pressure upon the bottom may be the same as that of the atmosphere?

CHAPTER X

SPECIFIC HEAT

85. By specific heat is meant the quantity of heat necessary to raise the temperature of a substance one degree compared with the amount of heat necessary to raise the temperature of an equal weight of water one degree.

Place 1 lb. of shot in a test tube, and 1 lb. of iron filings in another similar tube. Raise both to the same temperature by placing them in a vessel of hot water. Into each tube pour equal weights of water that has been cooled to 32° F. by means of ice. Take the temperature of the water in each and it will be found that the filings have given the water the greater amount of heat, as is shown by the higher temperature of the water in the tube containing the filings.

This experiment shows that iron has a greater amount of heat than lead at the same temperature.

86. Heat Capacity.—If equal weights of water, iron and mercury are so placed that each will receive as many heat units per minute as the other, at the end of a given time a thermometer will show that the mercury has been warmed through about 30 times and the iron about 9 times as many degrees as the water. This shows that a given weight of mercury requires about $\frac{1}{30}$ and an equal weight of iron $\frac{1}{9}$ as much heat to warm it one degree as an equal weight of water requires; therefore all substances do not have the same heat capacity.

Water being the standard the heat capacity of all substances are compared with its heat capacity, from which we get a set of ratios known as specific heats.

The following table gives the average specific heat of the most common substances, water being the standard:

TABLE OF SPECIFIC HEAT

Air (at constant pressure)	0.237
Water	1.000
Alcohol	0.620
Copper	0.091
Iron	0.113
Lead	0.031
Mercury	0.033
Silver	0.056
Ice	0.502
Steam	0.480
Aluminum	0.214
Tin	0.055
Zinc	0.094
Hydrogen (at constant pressure)	3.406

87. Measurement of Specific Heat.—A convenient method of measuring the specific heat of a body is the METHOD OF MIXTURE. When two bodies that are at different temperatures are put together the temperature of one will fall and that of the other will rise until they reach the same temperature. It will also be noticed that *the heat absorbed by the cool body* in heating is exactly the amount given out by the hot body in cooling. This principle may be stated in its simplest form as follows:

HEAT GAINED = HEAT LOST. The quantity of heat absorbed by the cool body in heating = mass × change in temperature × specific heat.

The quantity of heat given out by the hot body in cooling = mass × change in temperature × specific heat. Thus,

$$M = \text{mass};$$
$$t = \text{temperature change};$$
$$s = \text{specific heat};$$
$$Mts = M't's'.$$

EXAMPLE.—Two pounds of fine shot at 90° were poured into 1 lb. of water at 15°, and the resulting temperature was 20°. What is the specific heat of the shot?

Since the specific heat of water = 1

$$1 \times 5 \times 1 = 2 \times 70 \times s;$$

therefore,

$$s = \frac{5}{140} = .036-, \text{ specific heat of the shot.}$$

If the same quantity of heat is imparted to equal weights of water and fine shot the temperature of the shot will be about 28 times higher than that of the water:

$$\frac{\text{Specific heat of water}}{\text{Specific heat of shot}} \text{ or } \frac{1}{.036} = 28-.$$

With the exception of the gas hydrogen, water has the highest heat capacity—that is, the largest specific heat of all substances.

On this account water is well suited for conveying heat in the warming of buildings. For a similar reason the presence of a large quantity of water prevents a rapid change in the temperature of the air in contact with it, hence large bodies of water moderate the climate in their vicinity.

QUESTIONS

1. When two liquids having different temperatures are mixed, what is the relation between the quantity of heat lost by the warmer and the quantity of heat gained by the cooler liquid?

2. What is the meaning of specific heat?

3. If 12 lbs. of water at 16° F. and 72 lbs. of metal at 100° F. when mixed give a final temperature of 30° F., find the specific heat of the metal.

4. A piece of nickel at 100° F. was dropped into an equal weight of water at 32° F. and the resulting temperature was 10°. Find the specific heat of the nickel.

5. If an equal weight of water and iron at the same temperature be so placed that each receive the same amount of heat per minute, after five minutes which will be the higher in temperature?

6. What substance is used as the standard for computing specific heat?

7. The specific heat of iron is higher than lead. How would you prove this statement?

8. If equal masses of water, iron and lead are so placed that each receive the same number of heat units per minute, (*a*) which will show the highest temperature? (*b*) the lowest?

9. Why is water well suited for conveying heat in the warming of buildings?

10. Would alcohol be a better heat conveyor than water? Why?

11. A piece of silver at 194° F. weighing 200 ozs. is put into a volume of water at a temperature of 50° F. If the resulting temperature is 64.76° F., what is the weight of the water?

Sp.ht. $\times$ mass $\times$ temperature change =

sp.ht. $\times$ mass $\times$ temp. change

Therefore,

$$(.056 \times 200) \times (194 - 64.76) \div (1 \times 64.76 - 50) =$$

98 ozs., wt. of water.

CHAPTER XI

AIR ANALYSIS

88. Collection of Samples of Air.—After sealing a mine or a section of it for the purpose of extinguishing a fire there is always some anxiety, and it is desirable to know the effectiveness of the stoppings in excluding air and whether or not the fire is spreading. In order to determine this, samples of the imprisoned atmosphere should be obtained at regular intervals. The samples are best obtained in ordinary 4-oz. bottles; ground glass, or rubber stoppers should be used, if ground glass stoppers are used they should be greased with vaseline, and after the sample is taken the stopper is turned round until no air-spaces are visible in the vaseline.

For the purpose of taking samples and determining the temperature and pressure of the enclosed air a pipe provided with a valve should be placed in each stopping. The sample can then be collected by means of a small hand pump, pressures can be determined with a water gauge, and temperatures can be taken with a thermometer inserted through the pipe. If the stoppings are tight the fact is shown by a depletion of the oxygen behind them, and the lack of pressure as indicated by the water gauge.

If the bottle in which the sample is taken is wet and dirty, an appreciable amount of carbon dioxide may appear and the oxygen disappear. In a sample of air obtained by the writer

in a dirty bottle, using water as the displacing fluid, it was found after thirty days that the carbon dioxide increased to 4 per cent while the oxygen dropped to 16.7 per cent, a sample of the same atmosphere collected in a dry and clean bottle showed a carbon dioxide content of .7 per cent and that of oxygen 20.46 per cent. If the bottle is clean and wet the carbon dioxide may partially or wholly disappear. If the atmosphere is to be examined for methane only, water may be used as the displacing fluid in collecting the sample, because water has no appreciable solvent action upon methane, but the carbon dioxide in a sample collected by this means will be less than the truth. Pure water absorbs approximately its own volume of carbon dioxide at normal temperature and pressure.

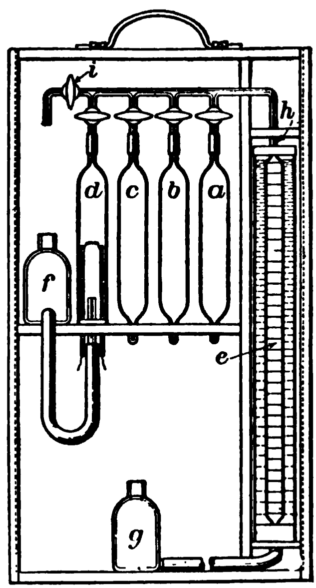


FIG. 13.

89. Directions for Using Orsat Apparatus.—The gas burette, *e*, Fig. 13, is attached to the leveling flask *g*, which is filled with water slightly acidified with sulphuric acid. By raising *g*, the burette *e* is filled with water to the mark *h*, while the burette is being filled with water the air is expelled through the stopcock *i*. The burette has a capacity of 100 c.c. and is graduated in 0.2 c.c.

Pipette *a* contains a potassium hydroxide solution for the removal by absorption of carbon dioxide; pipette *b* contains alkaline pyrogallate solution for the removal of oxygen; pipette *c* contains ammoniacal cuprous chloride solution for

the removal of carbon monoxide. The slow-combustion pipette *d* is used for burning the methane in the sample; this pipette contains distilled water slightly acidified with sulphuric acid.

Before beginning an analysis the solution in the pipettes *a*, *b*, *c*, and *d* are brought exactly to the mark on the capillary glass tubes of the pipettes. This is accomplished by the proper manipulation of the leveling bottle connected to the burette. The stopcocks on *a*, *b*, *c*, and *d* are then closed. *i* is now opened and the burette *e* is filled with water to the point *h* by raising the leveling bottle *g*, *i* is now closed, and a rubber tube connection is then made between *i* and the sample container, as shown by Fig. 14, and the latter is placed in a vessel of water. The stopcock of the sample container and *i* are then opened, and the leveling bottle *g* lowered until the water in the burette is lowered to about the 30 c.c. mark, the leveling bottle is again raised until the water in the burette reaches the mark *h*, the stopcock *i* being so arranged that the partial sample thus expelled will flow through the stem of stopcock *i*. The object being to clear the capillary tube and the rubber connection of any pure air they might have contained. The stopcock *i* is again opened and the leveling bottle lowered to the lowest division on the burette. The stopcock *i* is then closed and the gas in the burette is measured at atmospheric pressure by holding the leveling bottle in such a position that the surface of the water in the bottle is on line with the water in the burette. About two minutes is allowed for drainage of water down the sides of the burette before the measurement is taken, in order to guard against a small error which would otherwise ensue.

After measurement the sample is passed into pipette *a* several times by raising and lowering the level bottle; this operation removes the carbon dioxide, the solution in *a*

is then brought exactly to the mark on the capillary stem, and after waiting the required time for drainage in the burette the sample is measured. The loss in volume shows

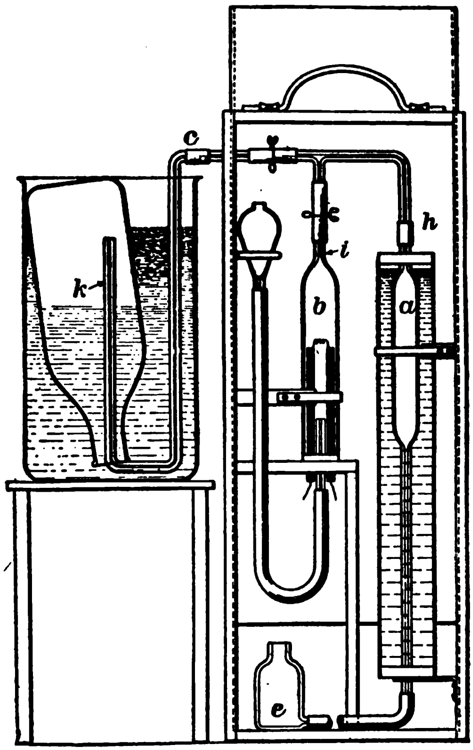


FIG. 14.

the amount of carbon dioxide absorbed by the potassium hydroxide solution.

The sample is then passed into the pipette *b* for the removal of oxygen. The sample is passed back and forth several times between burette and pipette in the same

manner as when determining carbon dioxide. The alkaline pyrogallate solution does not, however, remove the oxygen from a gas mixture as rapidly as the potassium hydroxide solution removes carbon dioxide, therefore the sample must be kept in contact with the solution for a longer time.

After the contraction in volume due to the absorption of oxygen has been noted the sample is then passed into pipette *c* for the removal of carbon monoxide. If after several passages of the sample in any pipette no difference in volume is observed the absorption of the gas may be considered complete.

Each gas should be completely removed in the pipette provided for its removal before the sample is passed into the next pipette, because, any gas remaining unabsorbed in the pipette provided for its absorption, if not fully, is to some extent absorbed in the pipettes provided for the absorption of other gases.

If the sample contains less than an explosive proportion of methane it is diluted with air by lowering the leveling bottle of the burette and opening the stopcock *i* to the outside air until the volume in the burette is 100 c.c. or nearly so. After the sample in the burette is measured it is passed into the slow-combustion pipette *d*, and the platinum wire therein heated to a white heat; this can be accomplished by the use of two ordinary dry cell batteries; after the expiration of about two minutes the methane in the sample may be considered completely oxidized. The pipette is then allowed to cool and the sample is passed back into the burette by manipulating the proper leveling bottle; the contraction in volume due to the burning of methane is then measured. The sample is then passed into the pipette *a* in order to determine the carbon dioxide due to the burning of methane. The carbon dioxide due to the

burning of methane should be equal to one-half the contraction due to combustion; if this does not hold good to within 0.2 c.c. a combustible gas other than methane is present, or an error has been made.

If the sample contains more than an explosive proportion of methane the gas remaining after the removal of carbon dioxide, oxygen, and carbon monoxide, is passed into the slow-combustion pipette *d* and the platinum wire heated to a white heat. Sufficient fresh air for the complete combustion of the methane is then drawn into the burette, measured, and passed into the pipette *d* at the rate of about 10 c.c. per minute, in this manner an explosive mixture of methane and air cannot exist, because the methane is slowly consumed before oxygen sufficient to produce an explosive mixture is forced into the pipette.

90. Analysis of Normal Mine Air.—Under ordinary conditions in well ventilated mines the return air and the air in the working places contain only small percentages of carbon dioxide and methane, while the oxygen content seldom falls below 20 per cent. For the analysis of which an apparatus containing three pipettes, namely, the potassium hydroxide pipette, the slow-combustion pipette and the alkaline pyrogallate pipette may be used. The sample is taken into the burette as formerly described, measured and passed into the potassium hydroxide pipette four or five times for the removal of carbon dioxide; after the reduction, in the sample, due to the removal of carbon dioxide is noted, the sample is then passed into the slow-combustion pipette and the platinum wire therein (No. 30 B. & S. gage) heated to a white heat by a current of about 4 or 5 amperes. About two minutes will be required to completely remove the methane, the sample should be forced back and forth several times between the burette and the pipette; when the pipette is sufficiently cool the sample

is brought back to the burette and the contraction in volume noted. The sample is then passed into the potassium hydroxide pipette for the removal of the carbon dioxide due to combustion. The contraction due to this absorption is then measured and the sample passed into the alkaline pyrogallate solution five or six times, where the oxygen is absorbed. To the oxygen determined by absorption is added the oxygen consumed in the burning of the methane.

RESULT OF ANALYSIS OF A SAMPLE OF AIR FROM A MAIN RETURN AIRWAY

	c.c.
Volume of sample taken	62.10
Volume after carbon dioxide absorption	62.05
Contraction due to carbon dioxide absorption	.05
Volume after combustion	61.40
Contraction due to combustion	.65
Volume after carbon dioxide absorption	61.08
Carbon dioxide due to combustion	.32
Volume after alkaline pyrogallate absorption	48.93
Partial oxygen	12.15
Oxygen consumed in burning methane	.65
Total oxygen	12.80
	Per Cent.
Carbon dioxide	0.08
Oxygen	20.61
Methane	.51
Nitrogen	78.80
	100.00

In case the sample contains CO_2, O_2, CO, CH_4, H_2, and N_2, the removal of the carbon dioxide, oxygen and carbon monoxide is accomplished in the manner formerly described. If the sample contains less than an explosive proportion of methane or hydrogen it is diluted with air or oxygen by lowering the level bottle after measuring; the sample is then passed into the slow-combustion pipette, and the platinum wire heated to a white heat, after about two

minutes the current is cut off and the pipette allowed to cool; the sample is then returned to the burette and measured, the carbon dioxide due to combustion is next determined, after which the hydrogen and methane are calculated from the combustion date.

A special tabulation of an analysis and the results of the calculation follows:

	c.c.
Volume taken for analysis	100.0
Volume after carbon dioxide absorption	97.4
Carbon dioxide in sample	2.6
Volume after alkaline pyrogallate absorption	81.6
Oxygen in sample	15.8
Volume after cuprous chloride absorption	80.8
Carbon monoxide in sample	.8
Volume taken for combustion	80.8
Oxygen added	18.0
Total volume	98.8
Volume after combustion	90.6
Contraction due to combustion	8.2
Volume after carbon dioxide absorption	86.8
Carbon dioxide due to combustion (methane)	3.8

$H_2 = 2/3[8.2 - 2(3.8)] = 0.4$ c.c.
$3.8 \times 2 = 7.6$
$8.2 - 7.6 = .6$
2/3 of .6 = 0.4 of c.c. hydrogen.

	Per Cent.
Carbon dioxide	2.6
Oxygen	15.8
Carbon monoxide	.8
Methane	3.8
Hydrogen	.4
Nitrogen	76.6

If the methane percentage is all that is required in an analysis of mine air, it is only necessary to measure the volume of air taken, pass it directly into the combustion pipette, and after combustion measure again. The methane present is equal to half the contraction. The percentage of which is found as follows:

Sample taken..................	20.00 c.c.
Volume after combustion.........	19.22
Contraction due to combustion....	.78

$\frac{.78}{2} = .39$ c.c. of methane in sample.

$\frac{.39}{20} \times 100 = 1.95$ per cent methane.

In case it is felt that the wire in the slow-combustion pipette was not hot enough to complete the combustion of the methane, the sample should be run back to the combustion pipette for a second combustion. It is desirable that the wire be heated to a white heat, in which case the methane will be completely burned in about two minutes.

When methane (CH_4) is the only combustible gas present the carbon dioxide due to combustion should be half the contraction on combustion; this, however, does not conclusively prove that other gases cannot be present. A mixture of equal parts of carbon monoxide and hydrogen or ethane and hydrogen would also show a contraction due to combustion double that of the carbon dioxide formed. As such mixtures do not occur in a mine, their possible existence need not be considered, and it may be assumed that the combustion took place according to the following equation:

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

The gaseous water ($2H_2O$) condenses to liquid water and ceases to occupy appreciable space, in view of which only three volumes of gas enter into the reaction, and only one volume results. The volume of methane present is evidently half the contraction due to combustion, or one-third of the total loss in volume after the carbon dioxide has been absorbed.

The carbon dioxide formed by reason of combustion will

vary with the kind of combustible gas present; if hydrogen be the gas under consideration the result of combustion will be as follows:

$$2H_2+O_2=2H_2O.$$

In this case no carbon dioxide is formed.

We will next consider the combustion of carbon monoxide which will take place in accordance with the equation

$$2CO+O_2=2CO_2.$$

The reaction of carbon monoxide with oxygen as expressed by the equation shows that two volumes of carbon monoxide unite with one volume of oxygen, and form two volumes of carbon dioxide.

To test the accuracy of the apparatus it is a good plan to make an analysis of outside air; if any leakage or other source of error exists it will plainly appear in the result of the analysis. The composition of pure outside air is about as follows:

	Per Cent.
Oxygen	20.93
Carbon dioxide	0.03
Nitrogen	79.04
	100.00

91. Black Damp.—The term "black damp" is generally understood by the miner to mean an accumulation of carbon dioxide; a more exact definition is, however, a mixture of nitrogen and carbon dioxide in proportions larger than those found in pure air.

When air enters a coal mine a gradual change in its

composition takes place, the extent of this change will depend on the amount of coal the air comes in contact with, that is, the length of the airways; the velocity at which the air moves and the gaseous nature of the coal seam are also important factors.

The result of an analysis of air taken from the face of a working place in an anthracite mine is as follows:

	Per Cent.
Carbon dioxide	.41
Oxygen	20.35
Nitrogen	79.24
	100.00

Recalculating the above analysis to show the air and black damp present, and the percentage composition of each. The percentage of air in the sample can be calculated from the oxygen percentage by multiplying by $\frac{100}{20.93}$.

Thus $\frac{100}{20.93} \times 20.35 = 97.22$ per cent of air. The total sample $100 - 97.22 = 2.78$ per cent black damp.

92. Laboratory Form of Apparatus for the Exact Determination of Methane.—The apparatus shown in Fig. 15 contains a burette similar to that used on Haldane's apparatus; its volume is 21 c.c., the bulb capacity is 15 c.c., and the capacity of the stem is 6 c.c. The burette has an attachment that compensates for small changes in temperature during the course of an analysis. The stem is graduated into hundredths of a cubic centimeter. The slow-combustion pipette *g* is similar to the pipettes in Figs. 13 and 14.

The sample is drawn into the burette in the same manner as shown in Fig. 14. After sweeping the air out

of the capillary tubing as heretofore described, about 21 c.c. of the sample is drawn into the burette and measured against the pressure existing in the compensating tube *c* by means of the liquid in the manometer *b*. A mixture of one part of glycerin and three parts of water is used in the manometer; because of the low density of the water it will not respond as readily to a slight movement of the mercury in the burette.

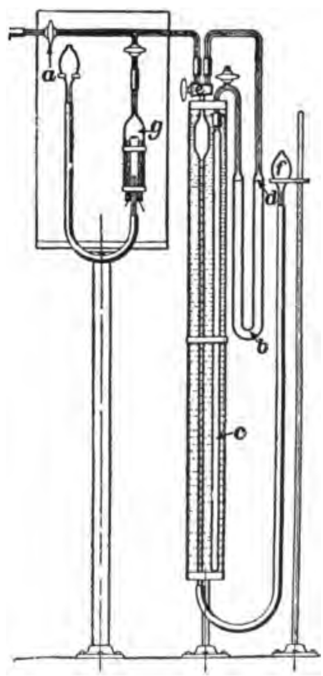


FIG. 15.

The glycerin solution in the manometer *b* is such that the surface of the liquid in both parts of the U tube is approximately at *d*. After the sample has been drawn into the burette, the burette stopcock *e* is turned so that communication is made between the burette and the manometer. By slightly raising or lowering the level bulb *f* the glycerin solution in the U tube is brought exactly to the mark *d*. The burette reading is then taken. The gas is then passed into the slow-combustion pipette and the platinum wire heated to a white heat. After combustion the sample is returned to the burette and the contraction noted. This contraction, divided by 2 and calculated to a percentage basis represents the proportion of methane in the sample.

93. Special Hints.—Before measuring and after each absorption, wait some stated time, say one or two minutes,

for the walls of the burette to drain, waiting the same time in all cases throughout the analysis, otherwise a slight error will result.

Heavy walled-gum tubing should be used on all connections, and the stopcocks should be well greased with vaseline.

The use of water in the burette and the slow-combustion pipette will interfere with accuracy if readings are not taken promptly when the sample contains carbon dioxide unless the water is previously saturated with the gas to prevent the absorption of carbon dioxide, the reverse of this is true in a case where air free from carbon dioxide is measured over water saturated with the gas, the volume being always increased by carbon dioxide which diffuses out of solution.

94. Preparation of Reagents.—Potassium hydroxide solution is prepared by dissolving 330 grams of potassium hydroxide in 1000 c.c. of distilled water. One cubic centimeter of the solution absorbs 40 c.c. of carbon dioxide.

95. The Alkaline Pyrogallate solution is prepared by dissolving 5 grams of pyrogallol in 15 c.c. of distilled water and 120 grams of potassium hydroxide in 80 c.c. of water. The two solutions are mixed in the pipette when ready to be used. The solution never deteriorates by merely standing in the pipette. A large number of analyses can be made before a renewal is necessary.

96. The Ammoniacal Cuprous Chloride is prepared as follows: 400 grams of cuprous chloride and 500 grams of ammonium chloride are dissolved in 1500 c.c. of distilled water. For use, the solution is mixed with ammonium hydroxide of a specific gravity of 0.90, in the proportion of 3 to 1.

Carbon monoxide is not absorbed by cuprous chloride solution as rapidly as oxygen is absorbed by the alkaline

pyrogallate solution, therefore a longer contact with the solution is necessary. It should also be remembered that acetylene, ethylene and oxygen are taken up by cuprous chloride solutions, and these gases must be previously removed before attempting to remove carbon monoxide.

A fresh solution of alkaline pyrogallate will completely remove the oxygen from an air sample in about two minutes when an Orsat pipette is employed and the sample passed back and forth between the burette and the pipette in order that the glass rods in the latter be kept covered with a fresh solution.

97. The Burrell Gas Detector.—By means of this instrument percentages of gas, lower than can be detected by a safety lamp, can be accurately determined inside the mine.

In the construction of the detector advantage was taken of the fact that methane, when it burns in complete combustion, produces water vapor and carbon dioxide, according to the following reaction:

Methane.		Oxygen.		Carbon Dioxide.		Water Vapor.
CH_4	+	$2O_2$	=	CO_2	+	$2H_2O$
1 vol.		2 vol.		1 vol.		2 vol.

Or, one volume of methane combines with two volumes of oxygen to form one volume of carbon dioxide and two volumes of water vapor. The amount of gas entering into the reaction is three volumes, and the amount that remains after the completion of the reaction, and occupies appreciable space, is one volume of carbon dioxide, because the water vapor formed condenses and does not occupy appreciable space. Therefore, as the water when in a vapor form equaled two volumes and after condensation it occupies practically no space it is evident the contraction is equal to twice the amount of methane that entered into

the reaction. The principle is the same as that on which accurate analysis of a gas is made in chemical laboratories.

The detector can be used for detecting combustible gases other than methane, it is only necessary to attach a scale properly calibrated for the gas that is being analyzed.

98. Instructions for Use of the Detector.—Unscrew cover piece *c* (Fig. 16) and pour clean water into the appa-

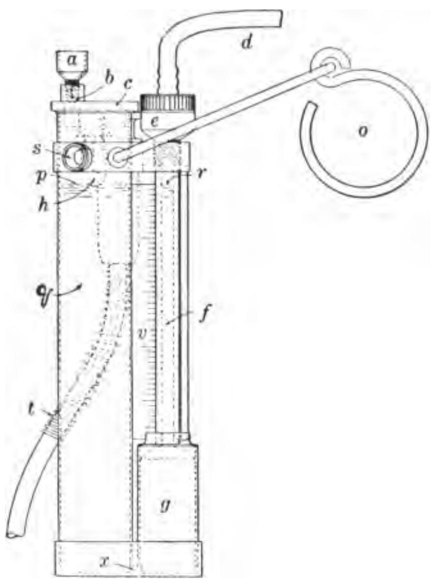


FIG. 16.

ratus until the water level in the glass tube rests at the point *r*. The water used should be about the same temperature as the surrounding atmosphere where the test is made. *c* is then replaced and valve *a* is opened by unscrewing a couple of turns. The operator then blows into the rubber tube *d*, until the water level at *p* rises to the valve *a*; when the water strikes the valve *a* a slight click can be heard.

The rubber tube *d* is then pinched, thus holding the water at *b*, and the instrument is held at the point where the sample is to be taken; the rubber tube *d* is then released, and the water fails to *p* and rises to *r*, assuming its original position; this process permits a sample of air to be forced into the apparatus through *a*, *b*.

The valve *a* is now closed and the electric current turned on for two minutes. The platinum wire glower must be white hot, a red heat will not do.

After two minutes the electric current is turned off and the instrument is shaken a few times to cool the gases by the water, whereupon the water level at *r* falls to a point that shows by the scale the per cent of methane originally in the sample. When shaking the instrument it should not be grasped at the top near the combustion chamber, as the temperature of the hand might cause an expansion of the air and effect the water level.

All tests should be finished at the place sample is taken, because a sample taken under certain conditions of temperature and pressure and carried to another part of the mine to be tested will very likely produce an error.

The pressure in a mine airway, through which air is passing, is different at all points along the airway.

The detector is so arranged that connection can be made between it and the storage battery of the Edison Electric miner's cap lamp.

The instrument is explosion proof. Flame cannot get out of the apparatus. If an explosive mixture is drawn into the apparatus, it explodes, but the only result is that pressure is exerted on the water level *p* and a few drops of water are forced out of the tube *d*. If this happens water must be replaced in the apparatus. A necessary requisite for good work is that the water levels before testing must rest at the point *p* and *r*, when *d* and *b* are open.

CAUTIONS.—(1) Do not use a glower or glass tube other than supplied by the manufacturers, which will have been approved by the Inventor, as the accuracy of the instrument is dependent on these two parts being standard.

(2) There must be no leakage of air around the combustion chamber. Test occasionally by placing instrument under water and blowing air through (*d*). Leakage will be indicated by bubbles.

CHAPTER XII

MINE VENTILATION

99. The amount of air passing through an ordinary mine is enormous; 200,000 cu.ft. per minute is quite common, and, in many of the larger mines, it reaches 500,000 cu.ft. per minute. The reasons for requiring such large volumes of air are: *first*, to supply those employed in the mine with sufficient oxygen to support life and *second*, to prevent the accumulation of firedamp.

Other agencies tending to vitiate the air of a mine are constantly in action, among which may be mentioned the burning of lights and the gases generated by blasting, and aside from this, carbon dioxide is escaping continuously from the pores of the coal as chambers and gangways are being driven. In connection with this, carbon dioxide is also formed by the action of the oxygen of the air on the carbon of the coal and timber; when carbon dioxide is formed in this way oxygen is taken from the air, the amount so taken being equal to the carbon dioxide produced. There is still a further loss in the oxygen content of the air passing through a mine by reason of the coal absorbing it.

With all the foregoing causes and conditions tending to vitiate the air current of a mine, the oxygen content seldom falls below 20 per cent, and the carbon dioxide rarely goes above 0.4 per cent.

The influence of water vapor in the air of a mine, or in a crowded room for that matter, presents a condition in itself requiring thorough ventilation.

The wet-bulb temperature is of direct hygienic impor-

tance when it is much above 60° F. In warm mines, the wet-bulb temperature is of great importance, and influences to a vast extent, not only the amount of work that can be performed, but the health of the worker.

Experiment has been conducted by confining several persons in a closed chamber until the oxygen content of the air fell to about 16 per cent and the carbon dioxide increased to over 4 per cent. At the same time the temperature of the enclosed air rose to 84° F., wet-bulb. The discomfort felt by those confined was relieved by starting an electric fan within, indicating that it was not the low oxygen or excess of carbon dioxide that caused the discomfort; it was the stagnant bodily heat. Relief was not obtained by one confined when breathing through a tube the pure air outside the chamber, nor was discomfort felt by one who, outside the chamber, breathed through a tube the impure air within.

When one considers the conditions making it necessary to ventilate a mine, and that the weight of the air passing through an ordinary mine in a year will exceed four million tons, the necessity for the proper construction of the airways through which this air must pass, together with a correctly proportioned fan, is apparent. The fans in use in the anthracite coal fields of Pennsylvania vary in size from 5 to 35 ft., operated by engines ranging from 20 to 250 h.p. and generating water gauge pressures from 0.5 to 5 in.

It has been the custom with the mine operator in the past, when ordering a ventilating fan, to furnish the fan manufacturer with certain dimensions, and the water gauge pressure against which the fan must act, in many cases the dimensions and water gauge so furnished being a duplicate of a fan already in operation at a mine and by means of which a large quantity of air is obtained; the purchaser

believed that a fan furnishing a large quantity of air for one mine will do equally as well if put in operation at another mine, when, as a matter of fact, each mine might require a fan having entirely different dimensions and water gauges.

In order to design and proportion a ventilating fan for the purpose of circulating a certain quantity of air through a mine per minute, it is necessary to know what pressure will be required to produce the desired velocity. At one mine a water gauge of 2 in. may produce 200,000 cu.ft. of air per minute, while at another mine the condition of the airways may be such that it would require a 6-in. water gauge to deliver the same quantity. If the diameters of the fans are the same, the fan producing the 6-in. gauge will need to run faster in order that there may be sufficient rim speed to produce the higher gauge, and if it is desired that both fans show the same volume ratio, its width must be narrower.

If the manufacturers of ventilating fans were more exact in their inquiry regarding the water gauge required for the ventilation of mines, there would be fewer good fans condemned.

The movement of air through a mine is caused by a difference in pressure between the intake and return airways. The velocity at which the air moves and the quantity of air passing through the airways of a mine will depend on this difference in pressure together with the resistance offered to the movement of the air by the rubbing surface of the airways.

A fan designed to produce 50,000 cu.ft. of air with a 1-inch water gauge might be placed at a mine, the airways in which may be of ample size and yet the quantity of air might be less than one-half the volume expected. This is due to the fact that the water gauge produced by the fan is not sufficient to overcome the mine resistance and produce sufficient velocity. Therefore it will readily

be seen that in order to cause air to move through this mine at a greater velocity the water gauge or pressure must be increased; this can only be done by the fan or other means employed for the purpose of producing ventilation.

100. Pressure Defined.—Air in motion in a mine is under the influence of three distinct pressures, namely, the VELOCITY, STATIC and DYNAMIC OR TOTAL PRESSURES.

The VELOCITY PRESSURE is that pressure which is required to create the velocity of flow.

The STATIC PRESSURE, sometimes termed the FRICTIONAL PRESSURE, is that pressure required to overcome the resistance offered to the flow.

The TOTAL PRESSURE, also termed the DYNAMIC OR IMPACT PRESSURE, is the sum of the static and velocity pressures.

QUESTION.—The water gauge produced by a fan is $\frac{1}{2}$ in., the airway is 5 ft. by 5 ft. What must be the rubbing surface in this mine to prevent the air from moving faster than 1 ft. per minute?

Solution.

$$s=\frac{pa}{kv^2} \text{ or } s=\frac{5.2\times\frac{1}{2}\times 25}{.00000002\times 1}=3{,}250{,}000{,}000 \text{ sq.ft.}$$

NOTE.—See Chapter XIII, for formulas and values for k, which is the coefficient of friction.

It is plain that in order to increase the velocity in this mine it will be necessary to increase the water gauge because in this case nearly the entire pressure generated by the fan is consumed in overcoming the mine resistance and only a small part of it is left to produce a velocity. Hence the static pressure required to overcome the resistance of the mine in question is equal to about $\frac{1}{2}$ in. water gauge, and any additional pressure that might be added will be wholly

consumed in producing velocity and overcoming the additional friction caused by the increased velocity.

The static water gauge or pressure can be found by the use of two water gauges, one of which should be piped into the airway with the end of the pipe opening at right angles to the direction of the air current, and the other gauge close to the same place with the end of the pipe opening pointing against the current so that the air can rush into the end of the pipe. While the gauges are in this position it will be noticed that one of the gauges will show a higher reading than the other. The difference in the readings is the velocity pressure, or the pressure producing the velocity.

FIG. 17.

WATER GAUGE.—The water gauge, Fig. 17, consists of a glass tube bent in the form of a U, both ends of which are open. When it is desired to measure the difference of pressure between two airways, one of the ends is inserted in a small hole bored in a door or brattice between the intake and return airways. When in this position the two ends of the gauge are subjected to two different pressures, the atmospheric pressure on the intake side if the fan is exhausting, and a pressure less than the atmosphere on the return side. This difference in pressure causes the water to drop in the tube on one side of the gauge and to rise a corresponding distance on the other side. The difference of the level of the water in the two tubes can be read by means of the scale attached, as shown in the figure.

The water gauge reading at an exhaust fan simply indicates the extent to which a vacuum is approached at the axis of the fan. In all cases where an exhaust fan is employed the atmospheric pressure forces the air into the intake and through the mine workings to the fan; it is then forced, by means of the fan blades, through the fan chimney into the atmosphere.

Air or other gases cannot be pulled or drawn through the airways of a mine, because the cohesion, or attractive power between the molecules of which gases are composed, is not strong enough to hold the particles of the gas together. Gases are always moved by a push or pressure.

When a blowing fan is employed, the atmospheric pressure forces the air into the fan, the fan wheel itself then gives the velocity to the air and forces it through the mine airways. It will be noticed, however, that for the same rim speed and under similar conditions, a fan when exhausting, and when blowing, will produce different water gauges, and the difference is always equal to the velocity pressure. When a fan is exhausting air from a mine, a negative static pressure must exist in the shaft in order to cause the air to enter the mine, while in the case of the blow fan, the fan blades give the velocity to the air. Under the conditions just described the blowing fan will always produce the smaller gauge. The difference will be equal to the velocity pressure.

101. Coefficient of Friction.—If a barometer is carried through the intake of a mine, traveling with the air, if an exhaust fan is used, the barometer will indicate that the pressure is reducing as the fan is approached.

In this manner, the amount of pressure consumed in producing ventilation in any airway or part of an airway can be found. For example, suppose it is desired to determine the amount of pressure consumed between two points

in an airway say 1000 ft. apart, the 0 of the altitude scale of the barometer should be set opposite 31 in. on the barometer dial, then, while standing at the point nearest the intake, in the airway under consideration, record the barometer reading in feet, which we will assume to be 1200; the barometer should then be carried to the other point where a second reading is taken, and which we will again assume to be 1175 ft., or a drop in pressure equal to 25 ft. If it is then found by calculation that the air weighs 0.08 lb. per cubic foot, the pressure per square foot consumed in producing ventilation in a 1000 ft. of this airway is 0.08 times 25 ft. or 2 lb. In case the section of airway in which the trial is made is not level any rise or fall in elevation must be considered in the calculation.

If it now be desired to establish a coefficient of friction for this airway it can be found as follows:

The length of the airway is 1000 ft., the pressure consumed is 2 lb. per square foot and assuming it is found by measurement that the airway is 10 ft. by 12 ft. and the velocity 500 ft. per minute:

$$\text{Then}\quad k=\frac{pa}{sv^2}=\frac{2\times120}{44000\times500^2}=0.000000021k.$$

ANEMOMETER.—The anemometer, Fig. 18, is an instrument used for measuring the velocity of air currents in mines and the ventilators of public buildings. The instrument consists of a delicately constructed fan wheel which revolves in a circular frame. Placed in an air passage the instrument registers automatically the rate at which the air is traveling through it. The revolutions of the wheel are recorded by means of several pointers or hands on the face of the instrument. The large hand makes one revolution for each hundred revolutions of the wheel.

One revolution of the large hand per minute is equivalent to a velocity of 100 ft. per minute.

Anemometers indicate satisfactorily velocities up to 10,000 ft. per minute, and each instrument is supplied with a chart of correction for different velocities.

102. Calculations.—The relation between fan speed, pressure, volume of air delivered and power required have

FIG. 18

been fully verified by tests and will be found convenient for reference by those interested in mine ventilation.

1. The volume of air delivered by a fan varies directly as the number of revolutions, resistance remaining the same; that is, if a fan running 80 R.P.M. delivers 100,000 cu.ft., how much air will be delivered if the revolutions are increased to 160?

Solution.—$80 : 160 :: 100{,}000 : X$. $X = 200{,}000$ cu.ft.

2. The water gauge or pressure produced by a fan varies directly as the square of the speed. If a fan running at 80 R.P.M. produces 1 in. water gauge, what water gauge will be produced if the revolutions are increased to 160?

Solution.—$80^2 : 160^2 :: 1$ in. $: X$. $X = 4$ in. w.g.

3. The water gauge or pressure required to force air through a mine varies directly as the square of the volumes. If with 1 in. water gauge 100,000 cu.ft of air are passing through a mine per minute, what water gauge will be required to pass 200,000 cu.ft. per minute?

Solution.—$100{,}000^2 : 200{,}000^2 :: 1 : X$. $X = 4$ in. w.g.

4. The power required to drive a fan varies directly as the cube of the revolutions. If it requires 25 H.P. to run a fan 80 R.P.M., what power will be required to run the fan 160 R.P.M.?

Solution.—$80^3 : 160^3 :: 25 : X$. $X = 200$ H.P.

5. The power required to ventilate a mine varies as the cube of the volume of air passing. If it requires 25 H.P. to circulate 100,000 cu.ft. of air through a mine, what H.P. will be required to circulate 200,000 cu.ft.?

Solution.—$100{,}000^3 : 200{,}000^3 :: 25 : X$. $X = 200$ H.P.

6. To find the size of motor or engine required to drive a fan under average mine conditions, multiply the number of cubic feet of air by the water gauge and divide this product by 4500. If a fan is delivering 100,000 cu.ft.

of air at 2 in. water gauge, what size motor or engine will be required to drive it?

Solution.—$\dfrac{100{,}000\times 2}{4500}=44.4$ H.P.

NOTE.—The above formula bases the equipment at 71 per cent mechanical efficiency, or, which is the same thing:

$$\frac{100{,}000\times 2\times 5.2}{33{,}000\times .71}=44.4 \text{ H.P. nearly.}$$

7. The horse-power of an engine is found by means of the following formula:

$$\frac{P\times L\times A\times N}{33{,}000}=\text{H.P.}$$

P = mean effective pressure;
L = length of stroke in feet;
A = area of piston in square inches;
N = number of strokes per minute.

EXAMPLE.—If a 16 in. by 18 in. engine is running 150 R.P.M. and the mean effective pressure is 40 lbs., what is the H.P.?

NOTE.—The number of revolutions at which an engine runs per minute multiplied by 2 will equal the number of strokes.

Solution.—$\dfrac{40\times 1\frac{1}{2}\times 201\times 300}{33{,}000}=109.6$ H.P.

8. The electric H.P. consumed by a direct-current motor is found by means of the following formula:

$$\frac{V \times A}{746} = \text{H.P.}$$

V = volts;
A = amperes;
746 = number of watts in one H.P.

EXAMPLE.—If a direct-current motor is using 100 amperes, and 250 volts, what is the H.P. input?

Solution.—$\frac{100 \times 250}{746} = 33.5$ H.P.

9. The mechanical efficiency of a ventilating equipment is the ratio of the actual H.P. consumed to the actual H.P. applied.

EXAMPLE.—If the actual H.P. of an engine is 44.4 and the effective H.P. is 31.5, what is the mechanical efficiency?

Solution.—$\frac{31.5}{44.4} = 71\%$ nearly.

10. The theoretical water gauge of a fan is computed by means of the following formula:

$$\frac{V^2 \times .078}{32.16 \times 5.2}.$$

V = peripheral speed of fan in feet per second;
.078 = weight of a cubic foot of air;
32.16 = g. acceleration due to gravity;
5.2 = pressure per square foot for 1 in. water gauge.

EXAMPLE.—If a fan is running $80\frac{1}{3}$ ft. peripheral speed per second, what is the theoretical water gauge?

Solution.—$\frac{80\frac{1}{3}^2 \times .078}{32.16 \times 5.2} = 3+$ins. water gauge.

11. The manometric efficiency of a fan is the ratio of the theoretical water gauge to the actual water gauge developed by the fan.

EXAMPLE.—If a fan running at a peripheral speed of $80\frac{1}{3}$ ft. per second produces an actual water gauge of 2 ins. and the theoretical water gauge is 3 ins., as found in Example 10, what is the manometric efficiency of the fan?

Solution.—$\frac{2''}{3''} = 66\frac{2}{3}$ per cent manometric efficiency.

12. The volumetric capacity of a fan is the ratio of the actual volume produced to the cubical contents of the fan multiplied by the number of revolutions.

EXAMPLE.—The cubical contents of a fan 10 ft. in diameter and 5 ft. wide is 392.7 cu.ft and running at 100 R.P.M. = 39,270 cu.ft. If the actual volume delivered by the fan is 78,540, what is its volumetric capacity?

Solution.—$\frac{78,540}{39,270} = 200$ per cent.

EXAMPLE.—The quantity of air delivered by a fan is 150,000 cubic feet per minute at a water gauge of $3\frac{1}{4}$ inches. If the efficiency of the plant is 65 per cent and the average steam pressure on the piston is 45 lbs. per square inch, what size engine will be required to do the work ?

Solution.—The foot pounds of work done on the air per minute are $150,000 \times 3.25 \times 5.2 = 2,535,000$.

The efficiency of the engine being 65 per cent, the foot pounds developed by the engine must be

$$\frac{2{,}535{,}000\times100}{65}=3{,}900{,}000 \text{ foot pounds per minute.}$$

The foot pounds developed by the engine are, piston speed in feet per minute × pressure per square inch on piston × area of piston. So that, taking the piston speed to average 400 feet per minute, the area of the piston is

$$\sqrt{\frac{150{,}000\times3.25\times5.2\times100}{65\times400\times45\times.7854}}=16.6 \text{ inches.}$$

103. The ventilating pressure may be expressed in inches of water gauge or in pounds per square foot. For instance, a water gauge of 2 ins. is equal to 2×5.2 or 10.4 lbs. per square foot. Should it be necessary to express the pressure per square foot in inches of water gauge, simply divide the pressure per square foot by 5.2. The number 5.2 is found by dividing 62.5, the weight of a cubic foot of water, by 12.

EXAMPLE.—If the water gauge is 2½ ins., (*a*) what is the pressure per square foot? (*b*) If the area of the airway is 30 sq.ft., what is the total pressure?

Solution.—(*a*) 2.5×5.2 = 13 lbs. per sq.ft.

(*b*) 30×13 = 390 lbs.

104. First Law of Friction.—*When the velocity remains constant the total pressure required to overcome friction varies directly as the extent of the rubbing surface.*

This law means that if the rubbing surface be doubled

the pressure must also be doubled in order to pass the air at the same velocity.

Example.—If an airway 10 ft. by 10 ft. and 1000 ft. long is increased in length to 2000 ft., how much additional pressure must be added to pass the same quantity of air?

Solution.—As the rubbing surface is doubled the pressure will therefore have to be doubled in order to pass the same quantity.

Example.—Find the rubbing surface of an airway, the sides of which are 10 ft. by 6 ft. and 2000 ft. long.

Solution.—$10+10+6+6=32$ ft. distance around the airway. $32\times2000=64{,}000$ sq.ft. *Ans.*

Example.—Suppose in the above example the sides of the airway were 15 ft. by 4 ft., the length being the same, what would be the rubbing surface?

Solution.—$15+15+4+4=38$ ft. distance around the airway. $38\times2000=76{,}000$ sq.ft. *Ans.*

Example.—If 20,000 cu.ft. of air passes per minute through an airway 1000 ft. long, what must be the increase in pressure to pass the same quantity through a similar airway 1500 ft. long?

Solution.—Since the rubbing surface is increased 1.5 times, it follows that, according to the first law of friction, the pressure must also be increased 1.5 times.

The form of the airway in a mine has considerable effect on the amount of rubbing surface, as will be shown by the following example:

Example.—Suppose there are three airways, the length of each 1000 ft.; one airway being 8 ft. by 8 ft., another 4 ft. by 16 ft., the third being circular, the diameter of which is 9.026 ft., what is the rubbing surface and area of each?

Solution.

1. $(8+8+8+8) \times 1000 = 32{,}000$ sq.ft. rubbing surface,
   Area $= 64$ sq.ft.

2. $(4+4+16+16) \times 1000 = 40{,}000$ sq.ft. rubbing surface,
   Area $= 64$ sq.ft.

3. $9.026 \times 3.1416 \times 1000 = 28{,}356$ sq.ft. rubbing surface,
   Area $= 64$ sq.ft. nearly.

105. Second Law of Friction.—*When the velocity and rubbing surfaces remain the same, the pressure required to force air through the airways of a mine increase and decrease inversely as the sectional area of the airways increase or decrease.*

This law means that if the velocity and rubbing surface remain the same, the pressure per square foot that will be necessary to maintain this velocity will increase as the sectional area decreases, and as the sectional area increases the pressure will decrease.

Hence, if the sectional area be reduced to $\frac{1}{2}$, $\frac{1}{4}$, etc., of its original area, the pressure per square foot must be increased 2, 4, etc., times in order to maintain the same velocity, and if the sectional area be increased 2, 4, etc., times the pressure per square foot necessary to maintain the same velocity will be reduced to $\frac{1}{2}$, $\frac{1}{4}$, etc., of the original pressure, the rubbing surface remaining the same.

Example.—If it requires a pressure of 10.4 lbs. to maintain a velocity of 1000 ft. per minute in an airway 8 ft. by 8 ft., what pressure per square foot will be required to maintain the same velocity in an airway 4 ft. by 4 ft., rubbing surface remaining the same?

Solution.—$8' \times 8' = 64$ sq.ft. area.
$4 \times 4 = 16$ sq.ft. area.

$$16 : 64 :: 10.4 : X, \text{ or } X = 41.6 \text{ lbs. per sq.ft.}$$

EXAMPLE.—If it requires a pressure of 5 lbs. per square foot to pass air through an 8 ft. by 10 ft. airway with a certain velocity, what pressure per square foot will be required to pass air through a 6 ft. by 8 ft. airway with the same velocity? The rubbing surface remaining the same.

EXAMPLE.—If it requires a pressure of 2 lbs. to force air through a 10 ft. by 10 ft. airway, what pressure per square foot will be required to pass air through an airway 5 ft. by 5 ft. at the same velocity? The rubbing surface remaining the same.

106. Third Law of Friction.—*The pressure required to overcome friction varies as the square of the velocities or quantities when the rubbing surface and the area of the airway remain the same.*

This law means that if the sectional area and rubbing surface remain the same the pressure per square foot will vary as the square of the velocity or quantity.

EXAMPLE.—If it requires a pressure of 5 lbs. to produce a velocity of 400 ft. per minute in a certain airway, what pressure will be required to produce a velocity of 500 ft. in the same airway?

Solution.—$400^2 : 500^2 :: 5 : X$, or $X = 7.8$ lbs.

EXAMPLE.—If 10 lbs. pressure produce a velocity 350 ft. per minute, what pressure will be required to produce a velocity of 700 ft. per minute in the same airway?

40 lbs. *Ans.*

Table K

TABLE OF PRESSURE PER SQUARE FOOT DUE TO DIFFERENT VELOCITIES OF THE AIR

Feet per Minute.	Pressure in Lbs. per sq.ft.
100	.006
150	.014
200	.025
300	.057
400	.102
500	.159
600	.230
700	.312
800	.408
900	.517
1000	.638
1500	1.437
2000	2.555
2500	3.991
3000	5.750
3500	7.825
4000	10.220
4500	12.937
5000	15.970
5500	19.298
6000	23.000
6500	26.976
7000	31.302
7500	35.937
8000	40.886
8500	46.155
9000	51.750
9500	57.744
10000	63.883

Force of Air.—To ascertain the force in pounds per square foot of an air current, multiply the square of the velocity of the air in feet per second by .0023.

QUESTIONS

1. What causes air to move through a mine?

2. A fan is running at 50 revolutions per minute, the water gauge being 1 in., and is producing 80,000 cu.ft. of air at a certain mine; a similar fan is in operation at another mine running at 50 revolutions and has a water gauge of 1 in. and is producing only 50,000 cu.ft. of air. What is the cause of the difference in quantity?

3. If the water gauge reading is $2\frac{1}{2}$ ins., what is the pressure per square foot?

4. The area of an airway is 60 sq.ft., the water gauge reading is 2 ins. What is the total pressure?

5. If the water gauge reading at a mine is $1\frac{1}{2}$ ins. and 5.2 lbs. pressure per sq.ft. are consumed in overcoming the mine resistance, what is the velocity?

6. Define static and velocity pressure.

7. What is the first law of friction?

8. An airway is $7\frac{1}{2}$ ft. high, $12\frac{1}{4}$ ft. wide and 5400 ft. long. What is the rubbing surface?

9. Does the mine resistance or the fan produce the water gauge?

10. A fan running at 50 revolutions produces a water gauge of 1 in. while ventilating a large mine. If the mine is cut off and the fan allowed to run in the open atmosphere at the same speed, what will be the water gauge?

11. If a fan running 50 revolutions per minute produces 50,000 cu.ft. of air per minute, what quantity will this fan produce when running 100 revolutions per minute?

12. If a fan running at 40 revolutions per minute produces a 2-in. water gauge, what water gauge will be produced when the fan is running 80 revolutions per minute?

13. If a 1-in. water gauge causes 50,000 cu.ft. of air

to flow through a mine, what water gauge will be necessary to pass 100,000 cu.ft. of air through the same mine?

1 . If it requires 20 H.P. to run a fan at 40 revolutions per minute, what horse-power will be required to run the fan at 80 revolutions per minute?

15. If it requires 10 H.P. to produce 50,000 cu.ft. of air per minute, what H.P. will be required to produce 100,000 cu.ft. of air?

16. A fan is delivering 50,000 cu.ft. of air per minute, the water gauge is 1 in. What power motor or engine is required to do this work?

17. A direct-current motor is consuming 100 amperes at a voltage of 500. What is the H.P.?

18. If a 10-ft. fan is running at 120 revolutions per minute, what is the theoretical water gauge?

19. If the actual water gauge produced by the fan in Question 18 is 1.3 ins., what is the manometric efficiency?

20. If a fan 12 ft. in diameter and 5 ft. wide, running at 100 revolutions per minute, is delivering 90,000 cu.ft. of air per minute, what is the volumetric capacity of the fan?

21. If you were about to order a fan to ventilate a mine, what points should be considered?

22. If a fan while ventilating a mine produces a 2-in. water gauge, what will be the water gauge if the mine is cut off and the fan run at the same speed in the open atmosphere?

23. How is the static pressure of a mine found?

24. If (in Question 22) the mine is cut off by means of a stopping, so arranged and constructed that the fan can get no air, and the revolutions remain the same, what will be the water gauge?

25. If it requires a pressure of 10 lbs. to produce a velocity of 500 ft. per minute in a certain mine, what

pressure will be required to produce a velocity of 800 ft. per minute?

26. If a 2-in. water gauge produces a velocity of 300 ft. per minute, what velocity will a 4-in. water gauge produce?

27. If it requires 40 H.P. to run a fan 80 revolutions per minute, how fast will the fan run if 50 H.P. is applied?

28. If a fan running at 80 revolutions per minute delivers 100,000 cu.ft. of air per minute, at how many revolutions per minute will it have to run to produce 200,000 cu.ft of air per minute?

29. If a 14 in. by 16 in. engine is running 100 R.P.M. and the mean effective pressure is 40 lbs., what is the H.P.?

30. If the effective horse-power of a ventilating equipment is 20.5 and the actual horse-power is 32, what is the mechanical efficiency?

31. If the effective horse-power of a ventilating equipment is 40 and the pressure producing ventilation is 10 lb. per square foot, what is the quantity?

32. The quantity of air delivered by a fan is 150,000 cu.ft. per minute and the water gauge is 2 ins. What is the effective horse-power?

33. If it requires 27 H.P. to produce 50,000 cu.ft. of air per minute, what quantity will 64 H.P. produce?

34. If 20 H.P. will produce 40,000 cu.ft. of air per minute, what horse-power will be required to produce 80,000 cu.ft. per minute?

35. A fan is 12 ft. in diameter and 5 ft. wide; it is running 100 revolutions per minute; the actual volume of air delivered by this fan is 80,000 cu.ft. per minute; what is its volumetric capacity?

36. A fan 10 ft. in diameter is running 100 revolutions per minute. What is the theoretical water gauge?

37. If the theoretical water gauge of a fan is 3 ins.

and the actual water gauge is $2\frac{1}{2}$ ins., what is the manometric efficiency of the fan?

38. There are two airways, one of which is 6 ft. by 6 ft. and the other 4 ft. by 9 ft., each being the same length, namely, 2500 ft. Through which airway will the larger quantity of air pass under the same pressure?

39. The water-gauge reading at a fan is 2 ins. If the static pressure at this mine is 8 lbs. per square foot, what is the velocity pressure?

40. The pressure produced by a fan is .4 of an inch water gauge, the mine airway is 4 ft. by 4 ft. What should be the length of this airway in order to prevent the air moving faster than 1 ft. per minute?

CHAPTER XIII

MINE VENTILATION

107. Mine Ventilation.—Every precaution should be taken to keep large airways, and a mine should not be permitted to get into a condition requiring more than a 3-in. water gauge pressure to ventilate it. However, a great number of old mines in operation to-day require a much larger gauge, the cause being due to long airways, small sectional areas and unequal splitting of the air current. The fans erected at those mines when the airways were short and little resistance offered to the movement of the air are now unfit for the work they are expected to perform.

It is the custom with some mine operators when ordering a fan to designate a certain size, even making out detailed specifications for it and state that the fan must perform a certain work in the number of cubic feet of air per minute and the water gauge against which the fan must work, when as a matter of fact the mine conditions require an equipment entirely different.

The matter of circulating and conducting air through the workings of a mine is a very easy matter if in the first place a fan be erected that will work economically against the mine conditions.

Ventilating Currents, How Produced.—Ventilating currents are produced by natural heat, by water falling, or a water-jet, by a steam jet, by a furnace and by a fan.

108. Natural Ventilation.—Natural ventilation is produced in a mine when there is a difference in elevation

between the intake and outlet airways and a difference in temperature between the two columns:

For the purpose of illustration, let Fig. 19 represent two shafts, the tops of which are at different elevations. During cold weather the shaft *AB* will be the downcast because the imaginary column of outside air from *A* to *E* is heavier than the air column from *C*, to level of shaft *AB*, the difference in weight being due to the difference in

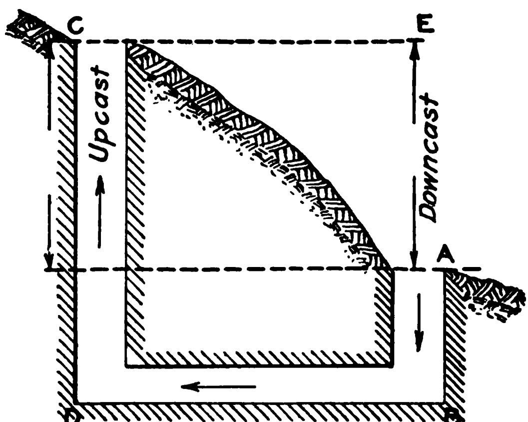


FIG. 19.

temperature. In the summer time the outside air being warmer than that of the mine the shaft *CD* will be the downcast, and the shaft *AB* the upcast. This system of ventilation works fairly well during the seasons of extreme heat and cold, but during the spring and fall when the temperatures inside and out are about equal, natural ventilation is ineffective.

109 Water and Steam Jet System of Ventilation.—This system of ventilation, while not very successful, is

sometimes applied in cases of emergency. The jet is so arranged that water is sprayed and allowed to fall into the intake shaft. In connection with this system a steam jet is sometimes used. The steam jet is arranged so as to blow in the upcast.

During the year 1852 a committee of the House of Commons at England reported: "That any system of ventilation depending on complicated machinery is undesirable, since under any disarrangement or fracture of its parts the ventilation is stopped or becomes inefficient.

"That the two systems which alone can be considered as rival powers are the furnace and the steam jet.

"Your committee is unanimously of opinion that the steam jet is the most powerful and at the same time least expensive method for the ventilation of mines."

110. Furnace Ventilation.—Furnaces are placed at the bottom of the upcast and are usually constructed of brick with air chambers on either side to prevent heating the surrounding strata. The heated air passing over the furnace and entering the upcast is, by reason of its rarefied state, lighter than the cool air in the downcast shaft and is consequently forced upward. The quantity of air produced by a furnace depends principally on the amount of heat generated together with the depth of the furnace shaft.

111. Ventilation by Means of Fan.—If a fan while working on a mine is exhausting air therefrom, the fan is then, due to centrifugal force, creating a partial vacuum at its center or axis; the extent of this vacuum depends on the peripheral or rim speed of the fan. The peripheral speed at which a fan should run depends altogether on its construction, and the water gauge required to ventilate the mine. While some fans may stand a rim speed of 16,000 ft. per minute, others will not stand more than 5000 ft. per minute.

When the inlet of the fan is connected to the mine the only air that can get to the fan must pass through the mine, and hence the ventilating current is maintained as long as the fan runs. When the fan is running the pressure of the air is always less at the inlet of the fan than outside, and the difference between this pressure and the pressure

A Robinson Reversible Fan.

of the atmosphere is the pressure producing ventilation, or the extent to which a vacuum is approached within the fan.

Many differently constructed fans are being used for the purpose of ventilating mines, the most prominent of which are those manufactured by the Robinson Ventilating Company, American Blower Company (Sirocco),

Jeffrey Manufacturing Company and others possessing similar features.

THE ROBINSON FAN.—The Robinson fan, one of the late developments in fans for mine ventilation, Fig. 20, shows the runner of this fan. The blades are curved to pass the air through the fan with the least friction or loss in power. By reason of the blade arrangement the air

FIG. 20.

is readily changed from its horizontal direction as it enters the wheel; hence, it is claimed, great economy is obtained by this fan. It is strongly constructed and is capable of standing any desired speed.

The following table, prepared by the Robinson Ventilating Company, shows the approximate quantity of air delivered by their fan, with favorable mine conditions, when running at different speeds and having different dimensions:

TABLE L

Diameter, Ins.	Width, Ins.	R.P.M.	Volume.
18	17	2500	21,000
24	20	1900	35,000
30	23	1500	45,000
36	26	1200	60,000
42	29	1000	75,000
48	32	800	90,000
54	35	700	100,000
60	40	650	120,000
66	45	575	140,000
72	50	500	170,000
84	55	420	210,000
96	60	350	260,000
120	65	275	350,000
144	70	225	420,000
168	75	200	450,000
192	80	180	500,000
216	85	170	575.000
240	90	160	650,000
264	92	150	700,000
288	95	140	800,000
300	100	130	900,000
312	105	120	1,200,000

The following illustration, Fig. 21, shows a Robinson disc fan operated by an electric motor and chain drive. It is used where the development does not justify the installation of a centrifugal fan and is highly efficient when placed in an airway to boost along feeble currents. It is easily installed and can be moved from place to place as the condition of the mine may require. In order to reverse the air current it is only necessary to change the direction of rotation.

THE SIROCCO FAN (Fig. 22).—The special advantages presented by this fan are: (1) large inlet area; (2) uniform action over the whole periphery, due to the large number

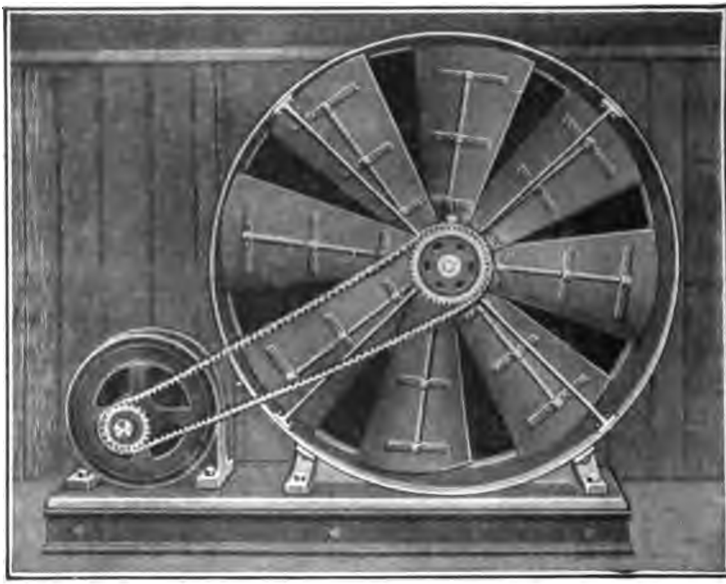


Fig. 21.

Fig. 22.

of blades; (3) absence of whirlpool motion of the entering air before reaching the fan blades, thereby avoiding the expenditure of power on unnecessary work; (4) the blades are so constructed and arranged that the power consuming eddies are minimized.

Instead of the work being done by 12 or 16 blades, as in the majority of old fans, the Sirocco has 128 blades in the double-inlet type of fan, thereby securing uniformity of action around the entire circumference.

Fig. 23 shows a single-inlet reversible fan and fan drift installed at a drift mouth, and Fig. 24 shows a double-inlet reversible fan on a shaft mine.

It frequently happens that a fan installed at a mine cannot create sufficient pressure to cause the proper volume of air to circulate through the remote parts of the mine. To remedy this difficulty a booster fan (Fig. 25) is sometimes installed at a convenient point in the airway. In all such installations, however, the pressure produced by the booster must be above the pressure of the air current at the point of installation. If the booster is unable to produce a greater pressure than is already in the air current, then it will be unable to increase the volume.

Table M shows the approximate capacities of various sizes of Sirocco fans against varying resistances. As stated, no definite rule can be given by which the quantity of air a fan will cause to flow through a mine can be calculated, unless the exact mine conditions are known. A fan listed in the tables, given herewith, as being capable of producing 150,000 cu.ft. of air per minute with a 2-in. water gauge might be placed at a mine in which the airways are such that the pressure is only sufficient to overcome friction and cause little or no velocity.

If economy and efficient ventilation are desired it is absolutely necessary that the manufacturer know the

Fig. 23.

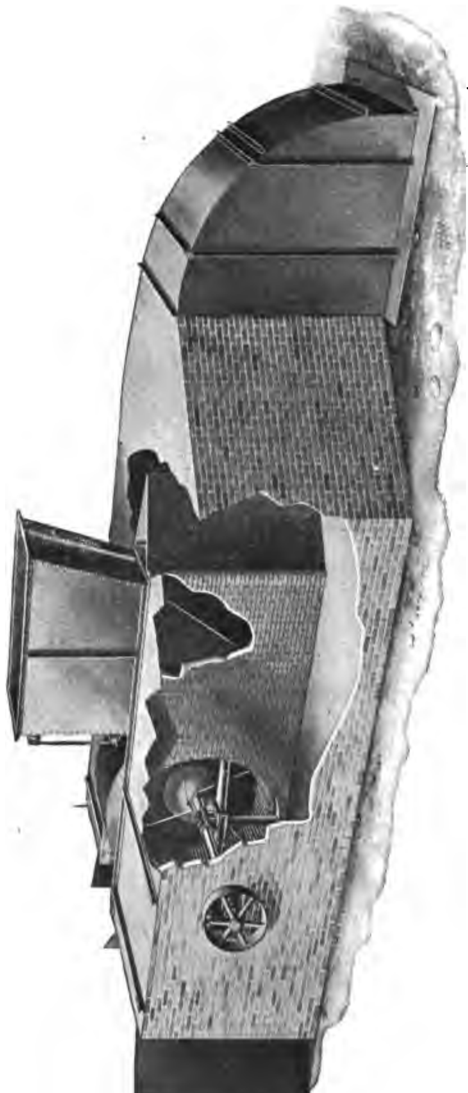
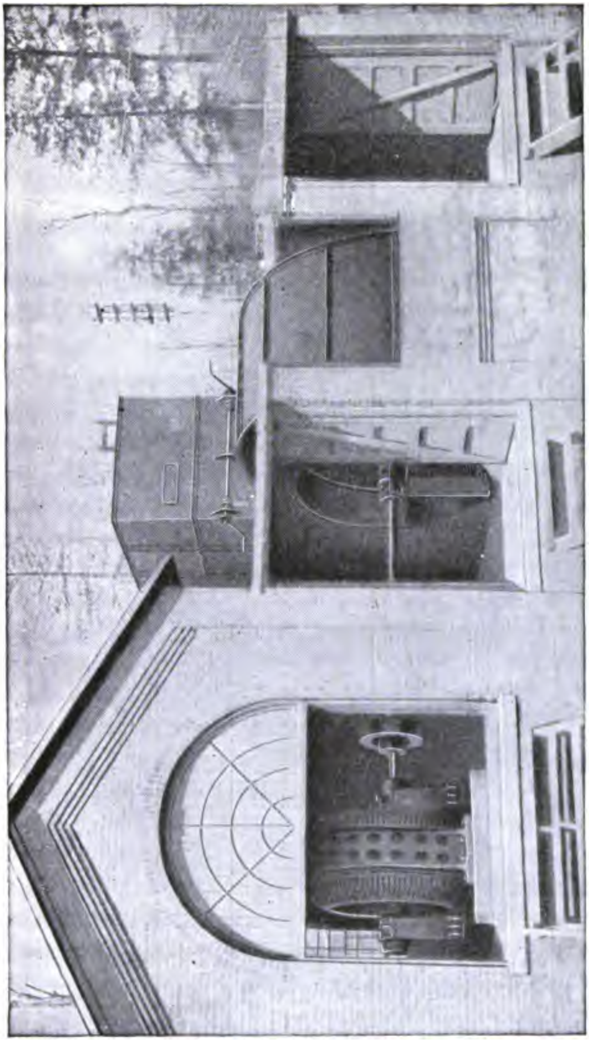


Fig. 24.

Fig. 25.



Sirocco Reversible Fan Acting as a Blower.

Table M

Volume Cu.ft. Per Min.	Static Pressure in w.g.	Approx. H.P. Required.	Size and Speed of Fan Wheel.			
			Single Inlet.		Double Inlet.	
			Diam. Width.	R.P.M.	Diam. Width.	R.P.M.
	ins.		ft. in. ft. in.		ft. in. ft. in.	
40,000	¾	8	7 0×3 6	124	5 0×5 0	172
	1	11	6 6×3 3	154	4 6×4 6	224
	1½	16	6 0×3 0	205	4 0×4 0	310
	2	21	6 0×2 6	235	4 0×3 6	358
60,000	1	16	8 0×4 0	124	5 6×5 6	185
	1½	24	8 0×3 0	156	5 6×4 6	224
	2	32	7 6×2 10	190	5 0×4 6	282
	3	48	7 0×2 6	250	5 0×3 8	346
80,000	1	21	9 0×4 6	102	6 6×6 6	154
	2	42	8 6×3 2	170	6 0×5 0	235
	3	63	8 0×2 10	220	6 0×4 0	288
	4	84	8 0×2 8	250	5 6×3 8	366
100,000	2	53	10 0×3 6	143	7 0×5 0	204
	3	80	9 6×3 2	182	6 6×4 4	270
	4	107	9 0×2 10	222	6 0×4 4	333
	5	133	9 0×2 8	248	6 0×3 8	376
125,000	2	66	11 0×4 0	130	8 0×5 8	176
	3	100	10 6×3 6	166	7 6×5 0	232
	4	133	10 0×3 2	200	7 0×4 8	285
	5	167	10 0×3 0	222	7 0×4 0	322
150,000	2	80	12 0×4 4	120	8 6×6 4	167
	3	120	11 6×3 10	151	8 0×5 4	220
	4	160	11 0×3 6	182	7 6×5 0	268
	5	200	11 0×3 4	202	7 6×4 8	298
175,000	2	93	13 0×4 8	110	9 6×6 8	149
	3	140	12 6×4 2	138	9 0×5 8	193
	4	187	12 0×3 8	168	8 6×5 4	236
	5	234	11 6×3 6	195	8 6×5 0	263

TABLE M—*Continued*

Volume Cu.ft. Per Min.	Static Pressure in w.g.	Approx. H.P. Required.	Size and Speed of Fan Wheel. Single Inlet. Diam. Width.		Double Inlet. Diam. Width.	
			Single Inlet. Diam. Width.	R.P.M.	Double Inlet. Diam. Width.	R.P.M.
	ins.		ft. in. ft. in.		ft. in. ft. in	
200,000	3	160	13 0×4 4	136	9 6×6 4	182
	4	214	12 6×4 2	160	9 0×5 8	222
	5	266	12 0×3 10	186	9 0×5 4	248
	6	320	11 6×3 8	214	8 6×5 0	288
250,000	3	200	14 6×5 0	120	10 6×7 0	166
	4	266	14 0×4 6	144	10 0×6 4	200
	5	334	13 6×4 2	166	10 0×6 0	222
	6	400	13 0×4 0	188	10 0×5 6	247
300,000	3	240	16 0×5 6	108	11 6×7 8	151
	4	320	15 6×5 0	129	11 0×7 0	182
	5	400	15 0×4 8	148	11 0×6 8	202
	6	480	14 6×4 6	168	10 6×6 4	232
350,000	4	374	16 6×5 4	122	12 0×7 4	168
	5	468	16 0×5 0	140	11 6×7 0	195
	6	560	15 6×4 10	157	11 0×6 8	224
	7	655	15 0×4 8	175	10 6×6 4	254
400,000	5	532	17 0×5 4	132	12 0×7 8	186
	6	640	16 6×5 2	148	11 6×7 4	214
	7	746	16 0×5 0	165	11 6×7 0	230
	8	854	15 6×4 10	182	11 6×7 0	244

mine conditions or the pressure that will be consumed in circulating the quantity of air desired.

Fig. 26 shows a Sirocco Ventura Disc Mine fan. The Ventura Disc Mine fan is the latest achievement in the development of this class of apparatus. It is especially adapted to the ventilation of drift mines and for develop-

FIG. 26.

FIG. 27

ment work or new operations. It should be carefully noted, however, that speed considerations limit the application of this type of fan to mines where a high water gauge is not required.

Jeffrey Fan.—Fig. 27 shows the extreme sizes and construction of the Jeffrey fan wheel. The high efficiency developed by this fan is primarily due to the relative

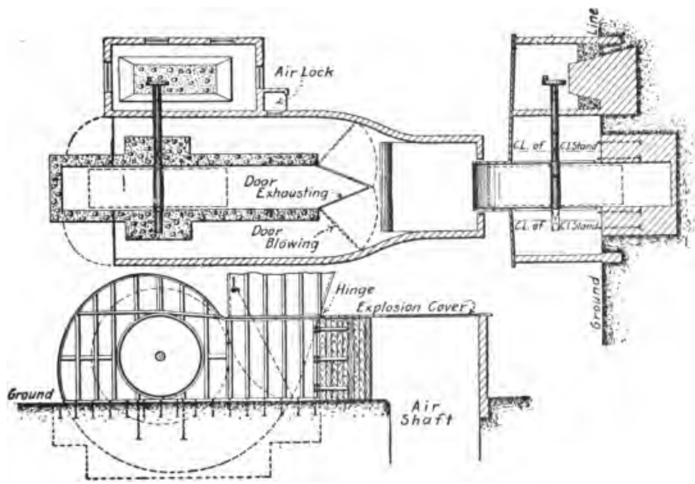


Fig. 28.

position and curvature of the blades, which are so arranged that the air is discharged in a forward direction, and each blade is backed up by an auxiliary blade which prevents eddy currents and the slippage of air.

The conical scoops, by their special form and position, prevent the gushing of air from the inlet when working against a high water gauge.

Fig. 28 shows plan and side view of a double inlet exhaust reversible fan with explosion cover, on a shaft mine.

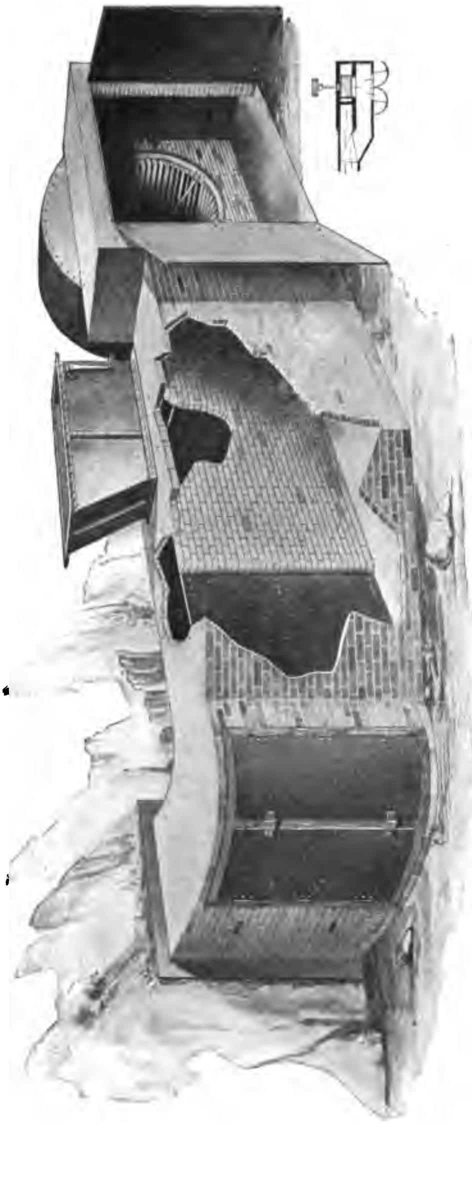
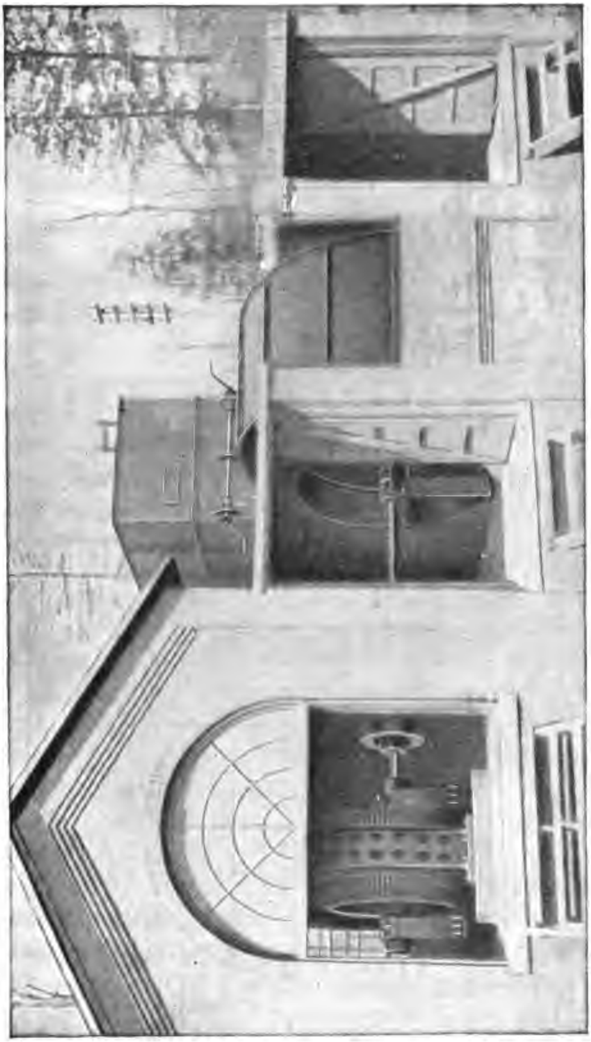


Fig. 23.

FIG. 24.

Fig. 25.



Sirocco Reversible Fan Acting as a Blower.

Any reduction in velocity brought about by an increase in the area of the airways will reduce the pressure and horse-power necessary to maintain the same quantity.

The following examples will better illustrate the extravagant use of power by reason of high velocities:

EXAMPLE 1.—The return air shaft of a mine is 10 ft. by 10 ft. in section and 1000 ft. deep; the quantity of air desired is 400,000 cu.ft. per minute. What pressure and horse-power will be required to force the air through the shaft?

$$p=\frac{ksv^2}{a}=\frac{.00000001\times 40{,}000\times 4000^2}{100}=64 \text{ lbs. per sq.ft.}$$

$$\text{H.P.}=\frac{400{,}000\times 64}{33{,}000}=776-\text{H.P.}$$

In the following example we will change the sectional area of the shaft, using the same quantity and depth:

EXAMPLE 2.—The return air shaft of a mine is 12 ft. by 15 ft. in section, and 1000 ft. deep; the quantity of air desired is 400,000 cu.ft. per minute. What pressure and horse-power will be required to force the air through the shaft?

$$p=\frac{ksv^2}{a}=\frac{.00000001\times 54{,}000\times 2222^2}{180}=14.8 \text{ lbs. per sq.ft.}$$

$$\text{H.P.}=\frac{400{,}000\times 14.8}{33{,}000}=179.3 \text{ H.P.},$$

or a saving under the second condition, of $776-179.3=596.7$ H.P.

At a cost of \$62.08 per horse-power per year a saving of 596.7 H.P. will amount to \$37,043.

The consumption of power in the ventilation of mines

TABLE P

Fan.	Diameter.	Width.	R.P.M.	Quantity of Air in Cu.ft. per Min.	Actual w.g.	Theoretical w.g.	H.P., Input.	H.P., Output.	Volumetric Capacity.	Mechanical Efficiency.	Manometric Efficiency.	Cost per H.P. Input per Hour.	Cost per H.P. Input per Year.
	Feet.	Ft. In.			Ins.	Ins.			Per Ct.	Per Ct.	Per Ct.		
1	20	9 4	90	75,660	1.8	4.1	51	21.4	28.6	41.9	43.9	.0143	$125.26
2	25	8	56	82,000	1.2	2.5	53	15.5	37.3	28.6	48	.0064	56.06
3	25	8	74	118,000	2.1	4.4	97	39	40.6	40.2	47.9	.0064	56.06
4	25	8	61	44,380	1.8	3	57	12.6	18.5	21.9	60	.0046	40.30
5	20	6	72	36,400	1.7	2.7	33	9.7	26.8	29.4	63	.007	61.32
6	15	4	68	40,850	1	1.3	$21\frac{2}{3}$	6.4	85	29.6	77	.007	61.32
7	25	8	80	114,000	3.3	5.1	117	59	36.3	50.4	64.7	.0045	39.42
8	20	6	100	282,744	4	5.1	222	178	150	78.4	78.4	.0065	56.94
				Averages	.....	.....	.....	.....	52.8	40.2	60.4	.00709	62.08

is an important item in the burden account, full of possibilities for saving. At a certain mine in Pennsylvania 324 H.P. is consumed by the ventilating equipment, while only 98 H.P. is effective in the ventilation of the mine; this involves a direct loss of 226 H.P. input or 226×$62.08 = $14,030 per year. (For cost per H.P., refer to Table P.)

Table P shows a comparison of several fans in actual operation. The facts contained therein were obtained by careful trial. In determining the cost per horse-power input, only the fuel, water and operating charges are used; no allowance has been made for maintenance or interest on investment.

112. Fan Action under Different Conditions.—There are many conditions which influence the speed and the horse-power required to maintain a constant fan speed, such as the humidity, the density and the volume of air passing through the fan.

If the specific gravity of pure dry air is assumed to be 1, the specific gravity of saturated air, or air having a relative humidity of 100 per cent, will be 0.62, that is a little more than one-half the weight of dry air under the same conditions of temperature and pressure. In practice, however, the relative humidity of mine air is seldom lower than 50 per cent, in consequence of which, the difference in the weight of air in the intake, and return airways of a mine caused by reason of aqueous vapor never reaches the maximum. However, it is possible for the difference in humidity to be such, in a mine where a large quantity of air is circulating, that there will be a difference of 2000 to 3000 lbs. in the weight of the air delivered by the fan each minute, and a greater or less horse-power will be required to maintain the same fan speed, depending on whether the relative humidity is low or high.

The volumetric efficiency of a fan is at its maximum when

it is running in the open atmosphere, when the air entering the fan is not retarded by any resistance other than that offered by the orifice of the fan. When working under this condition, the fan is then delivering its maximum volume and weight of air, and the maximum horse-power will be required. If the mine is now connected to the fan and the same horse-power applied, the speed of the fan will increase, and the density and volume of the air will decrease; this is because the mine resistance prevents the free flow of air to the fan. With the same power, under ordinary conditions, a fan will run faster when ventilating a mine, than it will while running in the open atmosphere.

If a door between the intake and return airways at the bottom of a shaft be opened and the air allowed to short-circuit, the engine, if not governed, will slow down.

113. Location of Fans.—It frequently happens that the ventilating equipment at a mine cannot produce a sufficient volume of air, and to remedy this difficulty, a second fan is installed and the two connected to the same upcast shaft. An auxiliary fan so located is of little practical value, the only advantage obtained, from an additional fan placed in this manner, is a saving of part of the pressure consumed in the fan drift and fan when one fan operated alone, a saving entirely too small to warrant the erection of the second fan.

If an exhaust fan, while ventilating a mine, produces a difference in pressure between the top of the intake shaft and the top of the return shaft equal to a 2-in. water gauge or 10.4 lb. per square foot, a certain quantity of air will be forced into the downcast shaft and through the mine workings to the fan, and under similar conditions of humidity, temperature and resistance, the quantity will not increase or decrease. Now, suppose an additional fan is connected to the top of the same upcast shaft and both are run at a

speed sufficient to generate a 2-in. water gauge, no advantage in pressure is obtained; the same difference in pressure that existed, namely, 10.4 lb. per square foot when one fan operated alone still exists when both are running together. As stated before, the only advantage gained in operating two fans in this manner is the slight saving in pressure in the fan drift and the fans; provided, however, that in the first instance the fan was of sufficient volume to handle the air forced through the mine by a 2-in. water gauge pressure.

In all cases where two fans are connected to a common upcast shaft, and receive their air through it, the rim speed of each should be such that the water gauges are equal; if this is not strictly observed, the volumetric efficiency of the fan having the smaller gauge may be reduced to unity. In fact, if the difference in the gauge readings is great, the fan having the larger gauge may obtain some of its air supply through the chimney of the other fan.

114. Booster Fans.—Booster fans are located under ground between the intake and return, or, at any point in the intake or return, to help along a feeble air current. A condition requiring their use exists where the movement of the air is broadcast, and where much of the air produced by the surface fan is lost by leakage.

A booster fan, placed in a mine for the purpose of assisting a fan located on the surface, will not increase the total quantity of air delivered by the surface fan unless it generates a greater pressure than that already generated by the surface fan; neither will it be of any local value unless it generates a pressure greater than that existing at the point of installation. The extent to which a vacuum is approached by a booster fan, installed for the purpose of assisting a surface fan, should be such that the air will more readily flow to it than take any other route that might be offered by reason of leakage or other cause.

For the purpose of increasing the volume of air in a mine, fans are sometimes placed in tandem; the increase in volume obtained by this method, however, does not warrant the expenditure. Fans placed in tandem, one at the top of the upcast shaft exhausting, and the other at the top of the downcast shaft blowing, are of little value to each other. Assume that an exhaust fan having certain dimensions is producing a 2-in. water gauge, and that, while so working, a certain volume of air is entering the downcast shaft at a certain velocity; if a force fan be now placed at the top of the downcast shaft and run at a speed sufficient to produce, say a 0.5-in. water gauge, it will not assist the exhaust fan, because the power already in the moving air, so caused by the exhaust fan running at a speed sufficient to generate a 2-inch water gauge, is far greater than that produced by the blowing fan. If the blowing fan be now run at a speed sufficient to produce a 2-in. water gauge, it is then only capable of producing a velocity in the downcast shaft slightly greater than that already existing.

If the rim speed of the blowing fan is further increased until the water gauge reading is 3 in., while the exhaust fan remains as formerly, producing a 2-in. water gauge, it will be found that the velocity of the air is increased, and this increase is entirely maintained by the blowing fan, because the velocity in the air is greater than that which the exhaust fan, with its 2 in. water gauge pressure is capable of producing.

In order to obtain the greatest efficiency and saving in horse-power, each fan should have an independent intake and return. With fans installed in this manner, the quantity of air can be doubled with twice the horse power, while, with fans working in tandem, or, while operating on, and receiving their air through the same intake and return, it will require about eight times the horse-power to double the quantity.

If a mine is already being ventilated by a fan and it is desired to replace this fan by one having a larger capacity, the pressure required to produce the larger volume can be calculated by means of the known facts, namely:—The pressure and volume produced by the fan already in operation and the desired new volume ($p : p_1 :: q^2 : q_1^2$).

If, however, the case is one where a fan is to be installed for the first time, further calculation is necessary. The airways of an ordinary mine may be divided into three classes, namely:

First, main splits, or those through which the whole volume of air passes;

Second, primary splits, or those that branch off the main split;

Third, secondary splits, or those that branch off primary splits.

It has been found by calculation and experiment that in the average anthracite mine about 85 per cent of the ventilating pressure is consumed in the main splits and the primary splits, and that where the air flows broadcast, the pressure consumed is hardly appreciable. Therefore, when calculating the pressure that will be required to force a certain volume of air through a mine it is only necessary to calculate for the main splits and the primary splits.

The value of the results obtained in this way will depend on the coefficient of friction. The coefficient is a very uncertain quantity and will vary greatly for different mines. The writer has found by many trials that the coefficient most applicable to different anthracite mines is 0.000000005.

115. Installation of Fan.—When about to install a mine-ventilating fan all the factors which go to make up the resistance encountered by the moving air should be considered; and in case the mine airways have not reached

the boundary lines a complete projection should be made of the proposed workings of the entire mine. The pressure necessary to circulate the required volume of air should then be calculated for the conditions which will exist when the workings have reached their limit, at which point the maximum resistance will be encountered by the air.

The question might now be asked, how to determine the pressure necessary to circulate a given quantity of air through a mine. It would be very difficult to calculate the pressure consumed in all the different airways, shafts and chambers throughout an entire mine; however, from actual trial, it is found that this is not necessary in order to obtain practicable results.

If it be decided that 150,000 cu.ft. of air per minute will be required to ventilate a certain mine it will be necessary, first, to calculate the pressure that will be consumed in producing this quantity, in order that the dimensions, speed, water gauge and horse-power of the fan can be determined.

The steps to be taken when determining the pressure required to pass this volume of air are as follows:

First, calculate the pressure required to pass the air through the main intake to the point where the first split branches off.

Second, calculate the pressure required to overcome the resistance of the main return airway from the point where the last split of air is returned into it, to the fan.

Third, calculate the pressure necessary to pass the required volume of air through the hardest primary split; in connection with this the resistance of the main intake airway, from the point where the first split is taken off to the beginning of the split under consideration must be included.

The pressure consumed in forcing air through the

hardest split will be equal to the pressure consumed in all other splits, because the resistance offered by the easier splits must be raised by means of regulators to that of the split consuming the most pressure. Therefore the sum of the three pressures, found as described, will be the pressure required to overcome the total mine resistance.

In addition to the pressure already found a reasonable allowance might be made for contraction of area due to brattices at the working faces.

Now we will suppose it is discovered by calculation that the pressure necessary to overcome the friction of the mine under consideration, and create sufficient velocity to circulate the required volume of air, namely, 150,000 cu.ft. per minute, is equal to a 3-in. water gauge.

It now remains to proportion a fan for a 3-in. actual water gauge and 150,000 cu.ft. of air per minute. In order to do this the peripheral speed required to create this water gauge must be found, but as the actual water gauge at a fan is seldom more than 80 per cent of the theoretical water gauge, it will be necessary to raise the 3-in. actual water gauge to the theoretical water gauge, which in this case will be 3.75 ins. Then,

$$V=\sqrt{\frac{3.75\times32.16\times5.2}{.078}}\times60=5380\text{ ft., nearly,}$$

peripheral or rim speed at which the fan must run per minute to create an actual water gauge of 3 ins.

It is now necessary to decide on diameter of fan desired. If a small diameter fan be employed and it is to be direct-connected to an engine, no doubt the operator would seriously object to the speed at which his engine must run to produce the required water gauge; then it will be necessary to go into a larger diameter of fan to get the gauge

at a rotated speed which would be acceptable. In case of a belt-driven equipment it is an easy matter to make the required reductions between engine, motor or fan pulleys.

However, we will select a 10-ft. diameter fan. The number of revolutions at which this fan must run to produce the required water gauge is found as follows:

$$\frac{\text{peripheral speed required to produce the water gauge}}{\text{circumference of fan}},$$

or

$$\frac{5380}{3.1416\times 10}=\frac{5380}{31.4160}=171 \text{ R.P.M.}$$

We must now find the width for a 10-ft. fan capable of discharging the required volume of air while running at 171 R.P.M. and at the same time show a reasonable volume ratio. Some manufacturers figure on a volume ratio of about 250 per cent. The meaning of this is, that if the volume of a fan is 100 cu.ft., it must deliver 250 cu.ft. of air for each revolution of the wheel in order to have a volume ratio of 250 per cent.

If, however, we reduce this volume ratio to 200 per cent to allow for any added friction that might interfere with the movement of the air from time to time, the width of the fan can then be found as follows:

$$\frac{q}{.7854\times D^2\times \text{R.P.M.}}=W,$$

or width for fan having 100 per cent volumetric capacity.

$$\frac{W}{2}=\text{width for fan 200 per cent volumetric capacity.}$$

Then,

$$\frac{150{,}000}{.7854\times 100\times 171}=11.17 \text{ ft., nearly,}$$

width for fan of 100% volume ratio,

$$\frac{11.17}{2}=5.58 \text{ ft.},$$

or say 6 feet, the required width for fan of 200% volume ratio.

To find the actual horse-power in the air (output):

$$\frac{150{,}000\times 3\times 5.2}{33{,}000}=71-\text{H.P.}$$

To find the horse-power (input) of motor or engine required to drive the fan:

$$\frac{q\times \text{w.g.}}{4500}=\frac{150{,}000\times 3''}{4500}=100 \text{ H.P.}$$

To find the mechanical efficiency of the ventilating equipment:

$$\frac{71 \text{ H.P.}}{100 \text{ H.P.}}=71 \text{ per cent mechanical efficiency.}$$

To find the manometric efficiency of the fan:

$$\frac{3'' \text{ w.g.}}{3.75'' \text{ w.g.}}=80 \text{ per cent manometric efficiency.}$$

Summary

Diameter of fan....................	10 feet
Width of fan......................	6 feet
Revolutions of fan per minute.......	171
Actual water gauge................	3 inches
Theoretical water gauge...........	3.75 ins.
Quantity of air delivered per minute..	150,000 cu.ft.

Volumetric capacity...............	200 per cent
Horse-power output...............	71
Horse-power input.................	100
Mechanical efficiency..............	71 per cent
Manometric efficiency..............	80 per cent

If it now be required to proportion a fan for a 5-in. actual water gauge instead of a 3-in., and 150,000 cu.ft. of air, using the same diameter of fan, namely, 10 ft., it is evident that the fan will have to run faster to generate the larger gauge; then if we figure on the same volume ratio it will be necessary to build the fan narrower.

116. Motive Column.—The motive column is a column of air in the downcast shaft the weight of which is the difference between the weight of the downcast and upcast columns; therefore if the length of the motive column be subtracted from the downcast column, the remaining portion of the downcast column will be equal in weight to the upcast column.

EXAMPLE.—At a certain mine there are two shafts 500 ft. deep. The temperature in the downcast shaft is 50° F., and the temperature of the upcast air is 150° F.; what is the motive column?

Solution.—$M=\frac{t-t'}{459+t}\times D.$

t = temperature of air in the upcast;
t' = temperature of air in the downcast;
D = depth of shaft in feet;
M = motive column.

$$\frac{(150-50)}{(459+150)}\times 500=82.1 \text{ feet motive column.}$$

If in the above example the atmosphere pressure is equal to 30 ins. of mercury and it is desired to find the pressure per square foot, the weight of a cubic foot of air in the downcast shaft must first be found. Thus,

$$W=\frac{1.3253\times B}{(459+t)},$$

in which B = the barometric pressure in inches;
t = temperature of the air in the shaft;
W = weight per cubic foot.

Applying formula:

$$W=\frac{1.3253\times 30}{(459+50)}=.0781 \text{ lb.}$$

Now if the height of the motive column is 82.1 feet and the weight of a cubic foot of air in the downcast shaft is .0781 lb., the pressure per square foot is:

$$82.1\times .0781=6.41 \text{ lbs.} \quad \textit{Ans.}$$

EXAMPLE.—The temperature of the air in a downcast shaft is 60° F. and in the upcast shaft 170° F.; the shafts are 900 ft. deep. If the barometer reading is 30 ins., what is the pressure per square foot?

EXAMPLE.—There are two shafts 600 ft. deep. The temperature in the upcast shaft is 180° F., and the temperature of the downcast air is 40° F.; what is the motive column?

EXAMPLE.—What is the weight of a cubic foot of air at a temperature of 60° F. when the barometer reading is 30 ins.?

117. Splitting the Air Current.—By splitting air means the dividing of the main intake current into two or more separate currents, the purpose of which is to ventilate

the different independent districts of a mine with air that is not vitiated by the smoke or gases from another district.

The advantages derived from splitting the air are as follows:

(1) A larger volume of air with the same power. The extent of the increase in volume will depend on how nearly equal the splits are.

(2) Purer air circulated through the working faces.

(3) An explosion or fire in one district is not likely to affect the other districts.

(4) A fall of roof affects only the section in which it occurs.

(5) The velocity of the air is kept within a reasonable limit in a greater portion of the mine.

Fig. 29 shows an air bridge or overcast. Such structures are necessary when it is desired to pass one current of air over or under another current. The sides and floors of air bridges are usually constructed of concrete. By the use of overcasts the main air current can be divided and conducted across one another for the purpose of ventilating the different districts of a mine. Sometimes an undercast bridge is employed for the same purpose as an overcast, but there is the liability of water flooding them and blocking the air.

The following examples will show the effect of splitting a continuous air current into several splits:

EXAMPLE.—An airway is 6 ft. by 10 ft. and 16,000 ft. long. What power will be required to circulate 24,000 cu.ft. of air through this airway?

Solution.

$$u=\frac{ksq^3}{a^3}=\frac{.0000000217\times 32\times 16{,}000\times 24{,}000^3}{60^3}=$$

711,066 ft.-lbs. *Ans.*

EXAMPLE 2.—Suppose the air in the above mine be so circulated and divided that we have four splits, each 4000 ft. long, the quantity of air being 24,000 cu.ft. and each airway is 6 ft. by 10 ft. in section; what power will be required to circulate the air?

Solution..

$$u=\frac{ksq^3}{a^3}=\frac{.0000000217\times128{,}000\times6000^3\times4}{60^3}=$$

11,110 ft.-lbs. *Ans.*

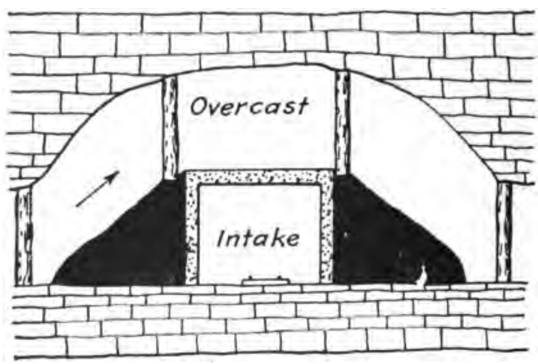


FIG. 29.

The above examples show a saving of 699,956 foot-pounds by reason of splitting the continuous current, as stated in the problem, into four equal splits; however, it is quite impossible in practice to divide a mine into equal splits or sections on account of the fact that a section of a mine may be in operation for a year or more before another section is started, consequently the splits will be unequal and the advantages obtained in power saved by reason of splitting will not be as great as in the case of equal splitting. The reason for this is that in nearly all cases of unequal splitting regulators are required.

118. Regulators.—Any partition constructed of boards, canvas, or any other material placed across an airway is termed a regulator. The usual method of construction is, however, the erecting of a board stopping across an airway (Fig. 30), in which stopping a shutter or door is so arranged that it can be moved in grooves and thereby allow the passage of the quantity of air desired.

Regulators as stated are principally used in cases of

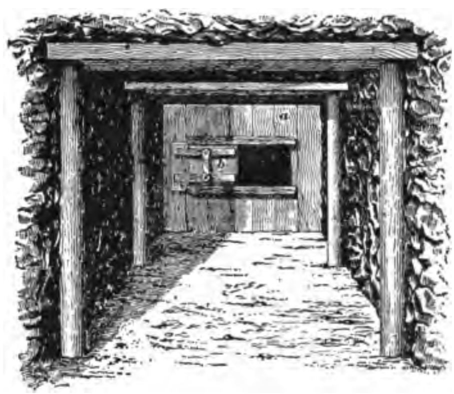


FIG. 30.

unequal splitting. Thus, if in a mine there are two splits, in one of which there are 700,000 sq.ft. of rubbing surface and in the other 400,000 sq.ft., it is evident that more air will pass through the split having the least rubbing surface; therefore, in order that equal quantities pass through each, if so desired, a regulator must be placed in the airway having the 400,000 sq.ft. of rubbing surface in order to cause the desired division.

A regulator placed in an airway is equivalent to lengthening the airway.

The introduction of a regulator in a mine increases

the mine resistance and reduces the total quantity of air; therefore regulators should not be used where it is possible to obtain the desired division of the air without them.

EXAMPLE.—Suppose we have two airways, A and B. A has an area of 30 sq.ft. and a rubbing surface of 66,000 sq.ft., and B has an area of 36 sq.ft. and a rubbing surface of 96,000 sq.ft. What quantity of air will pass in each split if the total quantity entering the mine is 50,000 cu.ft. per minute?

Solution.

$$A=q=\sqrt{\frac{a}{s}}\times a=\sqrt{\frac{30}{66,000}}\times 30=.6395,$$

$$B=q=\sqrt{\frac{a}{s}}\times a=\sqrt{\frac{36}{96,000}}\times 36=\frac{.6969}{1.3364},$$

$$A=\frac{.6395}{1.3364}\times 50,000=23,926q. \quad \textit{Ans.}$$

$$B=\frac{.6969}{1.3364}\times 50,000=26,074q. \quad \textit{Ans.}$$

EXAMPLE.—50,000 cu.ft. of air are entering a mine. If the current is divided into three splits of the following dimensions:

1st, 6 ft. by 6 ft. and 4000 ft. long;
2d, 5 ft. by 6 ft. and 3000 ft. long;
3d, 5 ft. by 5 ft. and 4000 ft. long,

what quantity will pass through each of the splits?

Ans. 1st, 19,597 cu.ft. per min.
2d, 17,980 cu.ft. per min.
3d, 12,423 cu.ft. per min.

Example.—If 20,000 cu.ft. of air pass per minute through an airway and it is desired to reduce the quantity to 8000 cu.ft. by means of a regulator, what must be the area of the opening if the difference of pressure on the two sides of the regulator is equivalent to $\frac{1}{4}$-in. water gauge?

Solution.—$A = \dfrac{.0004q}{\sqrt{W}}$,

in which A = area of opening in square feet;
q = quantity of air desired to pass;
W = difference of pressure in inches of water on the two sides of the regulator.

Applying formula:

$$A = \frac{.0004 \times q}{\sqrt{W}} = \frac{.0004 \times 8000}{\sqrt{\frac{1}{4}}} = 6.4 \text{ sq.ft.} \quad \textit{Ans.}$$

119. Resistance.—The several causes of resistance met with by the air while moving through a mine are as follows:

First. The resistance offered by the sides, top and bottom of the airway.

Second. The resistance due to turns in the airway.

Third. The resistance due to the sudden expansion and contraction of the airway.

Fourth. The resistance due to moving trips and cars standing in the airway.

Fifth. The resistance due to regulators.

First. The resistance offered to the air by reason of its rubbing on the sides, top and bottom of the airway is the most important source and is the heaviest consumer of pressure. In rough-timbered airways the resistance will be higher than in smooth airways.

Second. The resistance due to turns or bends in the air-

ways of a mine can be disregarded where the velocity of the air is low, but where the velocity is high and the air is forced around a right-angle turn, the amount of pressure consumed by reason of this source of resistance is serious. When bends are necessary they should be as large as the circumstances will permit so as to change the direction of the air gradually. Sudden changes in direction will destroy the velocity very rapidly and consequently reduce the volume.

Third. The resistance due to sudden or abrupt expansions and contractions of an airway, as in the case of turns, can be disregarded where the velocity of the air is low, but where the velocity is high the efficiency of the ventilating equipment is affected. According to certain laws governing the acceleration and retardation of air flowing through the airways of a mine, it is clear that if the movement of the air can be accomplished without abrupt change in the velocity or in the area of the airway, static pressure can be converted into velocity pressure. Contraction of area is sometimes necessary where air-bridges and door-frames are erected, but if the contraction is effected gradually when approaching the point of contracted area and gradually expanding after passing it the loss in volume will not be as great as where the contraction and expansion are abrupt.

The loss due to the sudden expansion of an airway for a short distance will be the same as that due to the sudden contraction, as the velocity-head in the moving air would be partly lost by the abrupt slowing down of the air, and additional pressure would have to be provided to re-establish the former velocity. The loss in volume by reason of this cause will increase and decrease as the squares of the velocities increase and decrease.

Fourth. The resistance due to mine cars moving or

standing in airways presents a source of resistance which cannot be removed, but the interference offered to the movement of the air can be reduced to a minimum if all junction points and other places where cars are allowed to stand in main airways be made of sufficient area to permit the free movement of the air.

Fifth. The resistance due to regulators can be removed only by equal splitting. In cases of unequal splitting it will be necessary to place regulators in the easier splits in order to restrict the quantity of air that will flow through them. The regulator is equivalent to lengthening the airway.

If in a mine composed of several unequal splits regulators are omitted, a natural division of the air will take place; the airway offering the least resistance will receive the most air.

QUESTIONS

1. State the different means by which ventilation is produced and describe each.
2. What is the motive column and how is it produced?
3. If the temperature of the air in the upcast shaft is 80° F. and the temperature in the downcast is 40° F., what is the motive column if the depth of each shaft is 600 ft.?
4. What is the weight of a cubic foot of air at a temperature of 30° F., the barometer being 30 ins.?
5. What is meant by splitting an air current?
6. What are the advantages of splitting the air current in a mine?
7. What is a regulator and to what is it equivalent?
8. Explain equal and unequal splitting?
9. Describe a mine in which it will be necessary to construct a regulator.

10. Does a regulator increase the mine resistance?

11. If you had a mine in which there were three equal splits, and the same quantity of air is desired for each, would regulators be necessary to produce an equal division?

12. If in the mine (in Question 11) the splits are unequal, how many regulators at most will be required?

Ans. Two, one split should always be free.

13. In a mine there are two splits, as follows:

A 5 ft. by 7 ft. and a rubbing surface of 10,000 sq.ft.;
B 8 ft. by 8 ft. and a rubbing surface of 20,000 sq.ft.

If 100,000 cu.ft of air enter the mine per minute, how will it divide in the above splits?

14. In a mine there are two splits, *A* and *B*; a regulator is placed in *A*; it later develops that more air is required in split *B*. Can the quantity in *B* be increased by adjusting the regulator? If so, how?

15. 10,000 cu.ft. of air are entering an airway per minute and it is desired to reduce this quantity to 5000 cu.ft. by means of a regulator. What must be the area of the regulator opening if the difference of pressure on both sides of the regulator is $\frac{1}{2}$-in. water gauge?

16. The upcast shaft is 300 ft. deep and the temperature of the air in it is 120° F.; the temperature of the downcast air is 45° F. What is the height of the motive column? *Ans.* 38.86 ft.

17. The air passing through a mine is equal to 100,000 cu.ft. per minute and is divided into two splits having equal cross-sections; the resistance of the splits are to each other as 5 is to 1; what quantity of air will pass through each?

Ans. 69,099 cu.ft. per min. in short airway.
30,901 cu.ft. per min. in long airway.

18. What is the weight of 100 cu.ft. of air when the barometer reading is 29.3 ins. and the temperature is 32° F.?

Ans. 7.9 lb.

19. What conditions are necessary in order to produce natural ventilation?

CHAPTER XIV

FORMULAS

120. Formulas and Their Application.—A formula is a group of symbols or letters designed to express clearly the operation of a rule. A formula may be expressed in words, but it is more convenient when symbols are used, they show at a glance the necessary operations required for the solving of problems.

The following formulas will be found convenient to the student when solving many problems pertaining to mine ventilation. The letters used are usually the first letters of the words they represent. The letters and their meanings are given below:

a = sectional area of airway in square feet;
H = horse power;

$$k = \text{coefficient of friction} \begin{cases} .000000005 \text{ (Walsh)} \\ .00000001 \text{ (Fairley)} \\ .00000002 \text{ (Atkinson)} \end{cases}$$

The coefficient of friction is the amount of pressure in pounds required to overcome the resistance offered by one square foot of rubbing surface when the air is moving at a velocity of one foot per minute.

l = length of airway in feet;
o = perimeter of airway in feet, or the distance around the airway;

p = pressure in pounds per square foot;
P = total ventilating pressure;
q = quantity of air in cubic feet per minute;
s = rubbing surface in square feet;
u = units of power in foot-pounds per minute;
v = velocity in feet per minute;
$w.g.$ = water gauge in inches of water.

NOTE.—The coefficient of friction may vary in ratio from 1 to 7 in different mines, and is a very uncertain quantity. The coefficients given above are those most commonly used for mine calculation.

FORMULAS FOR FINDING THE AREA

(1) $a = \frac{q}{v}$. (2) $a = \frac{P}{p}$.

(3) $a = \frac{ksv^2}{p}$. (4) $a = \frac{u}{pv}$.

(5) $a = \frac{H33,000}{pv}$. (6) $a = \frac{ksv^2q}{u}$.

(7) $a = \sqrt{\frac{ksq^2}{P}}$. (8) $a = \sqrt[3]{\frac{ksq^2}{p}}$.

FORMULAS FOR FINDING THE HORSE-POWER

(9) $H = \frac{pav}{33,000}$. (10) $H = \frac{Pv}{33,000}$.

(11) $H = \frac{pq}{33,000}$. (12) $H = \frac{u}{33,000}$.

(13) $H = \frac{ksv^3}{33,000}$.

Formulas for Finding the Coefficient of Friction

(14) $k=\frac{pa}{sv^2}$.

(15) $k=\frac{P}{sv^2}$.

(16) $k=\frac{pq}{sv^3}$.

(17) $k=\frac{u}{sv^3}$.

(18) $k=\frac{H33{,}000}{sv^3}$.

Formula for Finding the Length of the Airway

(19) $l=\frac{s}{o}$.

Formula for Finding the Perimeter of the Airway

(20) $o=\frac{s}{l}$.

Formulas for Finding the Total Pressure in Pounds

(21) $P=pa$.

(22) $P=ksv^2$.

(23) $P=\frac{H33{,}000}{v}$.

(24) $P=\frac{u}{v}$.

(25) $P=\frac{ksq^2}{a^2}$.

Formulas for Finding the Pressure in Pounds per Square Foot

(26) $p=\frac{ksv^2}{a}$.

(27) $p=\frac{P}{a}$.

(28) $p = w.g. \times 5.2.$

(29) $p = \dfrac{H33{,}000}{av}.$

(30) $p = \dfrac{H33{,}000}{q}.$

(31) $p = \dfrac{u}{av}.$

(32) $p = \dfrac{u}{q}.$

(33) $p = \dfrac{ksv^3}{q}.$

(34) $p = \dfrac{ksq^2}{a^3}.$

Formulas for Finding the Cubic Feet of Air per Minute

(35) $q = av.$

(36) $q = \dfrac{ksv^3}{p}.$

(37) $q = \dfrac{H33{,}000}{p}.$

(38) $q = \dfrac{u}{p}.$

(39) $q = a\sqrt{\dfrac{pa}{ks}}.$

Formulas for Finding the Rubbing Surface in Square Feet

(40) $s = ol.$

(41) $s = \dfrac{pa}{kv^2}.$

(42) $s = \dfrac{P}{kv^2}.$

(43) $s = \dfrac{pq}{kv^3}.$

(44) $s = \dfrac{H33{,}000}{kv^3}.$

(45) $s = \dfrac{u}{kv^3}.$

FORMULAS FOR FINDING THE UNITS OF POWER PER MINUTE

(46) $u = H33{,}000.$

(47) $u = pav.$

(48) $u = Pv.$

(49) $u = pq.$

(50) $u = ksv^3.$

FORMULAS FOR FINDING THE VELOCITY IN FEET PER MINUTE

(51) $v = \frac{q}{a}.$

(52) $v = \sqrt{\frac{pa}{ks}}.$

(53) $v = \sqrt{\frac{P}{ks}}.$

(54) $v = \frac{H33{,}000}{pa}.$

(55) $v = \frac{H33{,}000}{P}.$

(56) $v = \frac{u}{pa}.$

(57) $v = \frac{u}{P}.$

(58) $v = \sqrt[3]{\frac{pq}{ks}}.$

(59) $v = \sqrt[3]{\frac{H33{,}000}{ks}}.$

(60) $v = \sqrt[3]{\frac{u}{ks}}.$

FORMULAS FOR FINDING THE WATER GAUGE

(61) $w.g. = \frac{p}{5.2}.$

(62) Theoretical water gauge $= \frac{V^2 \times .078}{32.16 \times 5.2}.$

(63) Electric H.P. $= \frac{V \times A}{746}.$

121. Transposition of Formulas.—It is quite difficult to memorize all the formulas pertaining to mine ventilation. However, by memorizing a few of the larger group formulas nearly all the others can be written by means of transposing.

We have the formula $p=\frac{ksv^2}{a}$ from which it is desired to write the formulas for k, s, v, and a. Thus $k=\frac{pa}{sv^2}$, in which k is placed before the equality sign, p transferred to the position above the line which was occupied by k. All other quantities occupying a position above the line with k are placed below the line and the quantity a below the line is placed above the line with p.

Figures are sometimes used to aid the beginner in grasping the principles of transposing. Thus $16=\frac{4\times 8}{2}$, using the same quantities to find 4; $4=\frac{16\times 2}{8}$, also $8=\frac{16\times 2}{4}$ and $2=\frac{4\times 8}{16}$. With a little practice the transposition of formulas can be readily mastered and will eliminate the necessity of memorizing the great number used in reference to ventilation.

The formulas by which the following problems can be worked are indicated by number after each question. The coefficient used in obtaining the answers given for the problems is .00000002.

QUESTIONS

1. The quantity of air passing through an airway per minute is 50,000 cu.ft., the velocity is 500 ft. per minute. What is the area? (1) *Ans.* 100 sq.ft.

2. The total pressure producing ventilation in a mine

is 200 lbs. and the pressure per square foot is 2 lb. What is the area? (2) *Ans.* 100 sq.ft.

3. If in an airway having a rubbing surface of 40,000 sq.ft. the velocity is 500 ft. per minute and the pressure is 2 lb. per square foot, what is the area? (3) *Ans.* 100 sq.ft.

4. The pressure producing ventilation is 2 lb. per square foot, the velocity is 500 ft. per minute, and the units of work 100,000. What is the area of the airway? (4) *Ans.* 100 sq.ft.

5. The rubbing surface of an airway is 40,000 sq.ft., the velocity 500 ft. per minute, the units of work 100,000, and the quantity of air passing per minute is 50,000 cu.ft. What is the area? (6) *Ans.* 100 sq.ft.

6. If the rubbing surface of an airway is 40,000 sq.ft. and 50,000 cu.ft. of air are passing under a total pressure of 200 lbs., what is the area of the airway? (7) *Ans.* 100 sq.ft.

7. If a pressure of 2 lb. per square foot will produce a quantity of air equal to 50,000 cu.ft. per minute when the rubbing surface is 40,000 sq.ft., what is the area of the airway? (8) *Ans.* 100 sq.ft.

8. If it requires a pressure of 2 lb. per sq.ft. to pass air through an airway of 100 sq.ft. at a velocity of 500 ft. per minute, what is the horse-power? (9) *Ans.* 3.0303*H*.

9. If it requires a pressure of 2 lb. per square foot to produce 50,000 cu.ft. of air per minute, what is the horse-power? (11) *Ans.* 3.0303*H*.

10. The velocity of the air passing through an airway is 500 ft. per minute. If the rubbing surface is 40,000 sq.ft., what is the horse-power? (13) *Ans.* 3.0303*H*.

11. The pressure, area, rubbing surface and velocity are respectively 2, 100, 40,000 and 500. What is the coefficient of friction? (14) *Ans.* .00000002.

12. If it requires 2 lb. per square foot to produce 50,000 cu.ft. of air per minute, the velocity of the air being 500 ft. per minute, and the rubbing surface 40,000 sq.ft., what is the coefficient of friction? (16) *Ans.* .00000002.

13. The horse-power necessary to force air through a mine at a velocity of 500 ft. per minute, when the rubbing surface is 40,000 sq.ft., is 3.0303. What is the coefficient of friction? (18) *Ans.* .00000002 nearly.

14. If the rubbing surface of an airway is 40,000 sq.ft. and the perimeter 40 ft., what is the length? (19)
Ans. 1000 ft.

15. The rubbing surface of an airway is 40,000 sq.ft. and the length of the airway is 1000 ft. What is the perimeter? (20) *Ans.* 40 ft.

16. The pressure producing ventilation is 2 lb. per square foot. If the area of the airway is 100 sq.ft., what is the total pressure? (21) *Ans.* 200 lb.

17. If air is moving at a velocity of 500 ft. per minute through an airway having a rubbing surface of 40,000 sq.ft., what is the total pressure? (22) *Ans.* 200 lb.

18. If it requires 3.0303 horse-power to move air at a velocity of 500 ft. per minute through an airway, what is the total pressure? (23) *Ans.* 200 lb. nearly.

19. If 50,000 cu.ft. of air pass per minute through an airway, the area of which is 100 sq.ft. and the rubbing surface 40,000 sq.ft., what is the total pressure? (25)
Ans. 200 lb.

20. If the following conditions exist in an airway: Area 100 sq.ft., velocity per minute 500, rubbing surface 40,000 sq.ft., what is the pressure per square foot? (26)
Ans. 2 lb. per sq.ft.

21. If 3.0303 horse-power can produce 50,000 cu.ft. of air per minute, what is the pressure per square foot? (30)
Ans. 2 lb. nearly.

22. 50,000 cu.ft. of air pass through an airway at a velocity of 500 ft. per minute, the rubbing surface of the airway is 40,000 sq.ft. What is the pressure? (33)

Ans. 2 lbs. per sq.ft.

23. The area of an airway is 100 sq.ft., through which 50,000 cu.ft. of air pass per minute. If the rubbing surface of this airway is 40,000 sq.ft., what is the pressure per square foot? (34) *Ans.* 2 lb.

24. If a pressure of 2 lbs. per square foot will, in an airway having 40,000 sq.ft. of rubbing surface, produce a velocity of 500 ft. per minute, what is the quantity? (36)

Ans. 50,000 cu.ft. per min.

25. If the units of work consumed per minute equal 100,000 and the pressure 2 lbs. per square inch, what is the quantity? (38) *Ans.* 50,000 cu.ft.

26. The area of an airway is 100 sq.ft., the total pressure is 200 lbs. and the rubbing surface 40,000 sq.ft. What is the quantity of air passing per minute? (39)

Ans. 50,000 cu.ft.

27. If the area of an airway is 100 sq.ft., the pressure per square foot 2 lbs. and the rubbing surface 40,000 sq.ft., what is the quantity per minute? (39)

Ans. 50,000 cu.ft.

28. The length of an airway is 1000 ft. and the perimeter is 40 ft. What is the rubbing surface? (40)

Ans. 40,000 sq.ft.

29. The area of an airway is 100 sq.ft., the pressure per square foot is 2 lbs. and the velocity is 500 ft. per minute. What is the rubbing surface? (42) *Ans.* 40,000 sq.ft.

30. If it requires a pressure of 2 lbs. per square foot to force 50,000 cu.ft. of air through a mine at a velocity of 500 ft. per minute, what is the rubbing surface? (43)

Ans. 40,000 sq.ft.

31. If, in order to obtain a velocity of 500 ft. per minute,

3.0303 horse-power is required, what is the rubbing surface? (44) *Ans.* 40,000 sq.ft. nearly.

32. If the horse-power producing ventilation is 3.0303, state the required units of work per minute? (46) *Ans.* 100,000 units nearly.

33. State the units of power in foot-pounds per minute when the velocity is 500 ft. per minute, the pressure 2 lb. per square foot and the area of the airway 100 sq.ft. (47) *Ans.* 100,000 units.

34. State the units in foot-pounds per minute, when the quantity is 50,000 cu.ft. and the pressure 2 lb. per square foot. (49) *Ans.* 100,000 units.

35. The rubbing surface of an airway is 40,000 sq.ft., the velocity is 500 ft. per minute. What do the units equal? (50) *Ans.* 100,000 units.

36. What velocity will be produced by a pressure of 2 lb. per square foot in an airway having a rubbing surface of 40,000 sq.ft. and an area of 100 sq.ft.? (52) *Ans.* 500 ft. vel.

37. The horse-power producing ventilation is 3.0303, the pressure per square foot is 2 lb. and the area of the airway is 100 sq.ft. What is the velocity? (54) *Ans.* 500 ft. nearly.

38. The rubbing surface of an airway is 40,000 sq.ft., the quantity of air passing per minute is 50,000 cu.ft. and the pressure per square foot is 2 lb. What is the velocity per minute? (58) *Ans.* 500 ft.

39. The rubbing surface of an airway is 40,000 sq.ft., the units of power in foot-pounds per minute equal 100,000. What is the velocity per minute? (60) *Ans.* 500 ft.

40. If the pressure producing ventilation is 2 lb. per square foot, what is the water gauge? (61) *Ans.* .384 in.

41. If the peripheral speed of a fan is 100 ft. per second

and the weight of a cubic foot of air is .078, what is the theoretical water gauge? (62) *Ans.* 4.6 ins.

42. What horse-power is consumed by a direct-current motor if the voltage is 250 and the amperes 150? (63)

Ans. 50.2 H.P.

CHAPTER XV

MINE FIRES

122. Fires occur in a mine by reason of many different causes and under many different conditions. The principal causes of mine fires are open lights setting fire to dry timber or brattice cloth, gas feeders ignited by the use of a long flame powder, such as black powder and dynamite, and explosions of gas. Fires due to the above causes can be reduced to a minimum by the use of locked safety lamps and permissible explosives.

During the ordinary working of a colliery the leading officials should consider what steps should be taken to avoid mine fires, and should also make every possible preparation to deal with a serious fire should one occur. A few suggestions are given below:

1. Have a suitable range of water pipes from the surface to the different sections of the mine.

2. All pipe fittings, including connections for fighting mine fires, should have standard threads. Serious delays have occurred because fire-hose connections could not be attached to the mine pipe line.

3. A valuable device for fighting fires is that in use in the fire-fighting and training station in Germany. This is a special swing connection with gate valve attached which can be clamped anywhere on a pipe. By using a ratchet-drill a hole can be drilled through the open valve in a main that contains water under pressure. When the hole is finished the drill is withdrawn and the valve closed

until the hose connection has been made. When it is necessary to get water from a main at some point where there is no connection for the hose this device is valuable.

4. In addition to the safety lamps in ordinary use, have in readiness a supply of portable electric lamps.

5. Iron doors should be provided to close off the top of shaft or main intake to prevent smoke going into the mine, in case of a surface or shaft fire.

6. Breathing apparatus should be kept at each colliery and practice drills conducted frequently for the purpose of training selected employees in their use and establishing confidence in the apparatus.

7. A telephone system below ground, with connection to the surface, is an economy in the ordinary mine administration and is highly valuable in case of a mine fire, explosion or other accident when rescue work is to be performed.

8. Fire extinguishers have been successfully used in fighting mine fires, and a supply of them should be kept on hand.

9. All ventilating fans and fan drifts should be so constructed that the ventilating current could be quickly reversed. If a fire starts in the downcast or main intake a quick reversal will probably save the miners; however, reversing the ventilation should be done only after consultation and approval by those in charge.

Suggestions for Guidance after a Fire or Explosion

1. Send for the mine inspector, superintendent, and, in case men are injured or entombed, send for the rescue corps, doctors and ambulance corps.

2. In case of a shaft mine, if the ventilation is destroyed, use a steam jet in the upcast shaft and a water spray in

the downcast shaft for the purpose of establishing ventilation.

3. As to the question of running or stopping a fan in case of a fire in the downcast shaft or in the main intake, no general rule can be given, as a definite knowledge of local and general conditions in each case will be necessary. However, if the fan is kept running, the smoke will be forced through the workings and the imprisoned men will likely be suffocated; on the other hand, if the fan be stopped, fire-damp may accumulate and cause further disaster. But from past experience the indications seem to favor stopping the fan, especially at mines where the men would have to travel long distances through smoke and gases given off by the fire in order to get to a place of safety. As stated, a general knowledge of conditions must be had before the actual procedure in this case is definitely determined.

4. Do not, during the first twenty-four hours, spend time in recovering the dead if there is a chance to save life.

5. When possible, written instructions should be given to the leaders of the different exploring parties and every member of the party should obey the leader.

6. It should be remembered that a percentage of carbon monoxide too small to be detected by a lamp may be sufficient to cause death. The lamp should not be the final guide; mice and small birds are useful in detecting small percentages of this gas.

7. When selecting an exploring party, if breathing apparatus is to be employed, select only those who have been trained in the use of such apparatus. If an apparatus shows the slightest defect or is in any way uncomfortable it should not be used.

8. Never change the ventilation until after a consultation is first had with the proper officials; even then

it should not be changed or interfered with while men are in the mines, unless it be for the purpose of rescuing them.

9. In case an apparatus fails to work satisfactorily, the wearer, accompanied by at least two members of the party, should return to a place of safety, and at no time during the preliminary exploration work should the party be away from safety more than an hour.

10. An exploring party should never, on the first visit to a mine or section of a mine, establish ventilation—fires may exist. Feeders are usually found burning at the flame zone limit after an explosion.

123. Sealing a Mine Fire.—When it becomes necessary to seal a section of a mine to enclose a fire, all persons except those needed for the work should be removed from the mine. The usual procedure in connection with sealing a mine fire, especially if the mine is gaseous, is to erect temporary stoppings of brattice cloth or boards, and after several hours erect the permanent stoppings of stone, brick or concrete.

The question as to whether the return or intake stopping should be erected first or whether both should be erected simultaneously has been freely discussed and many varying opinions expressed.

It does not matter which stopping is erected first if the mine is non-gaseous. In gaseous mines the return stopping should be erected first, and to assure a reasonable degree of safety while performing the work the stoppings should be erected at a point which would not be seriously disturbed in case of an explosion.

If the stopping on the intake side of a fire is put up first, a partial vacuum created by the ventilating equipment then exists in the enclosed area and the gases generated by the fire are drawn away from it, likewise any

fire-damp that might be on the inside will move in the direction of the fire, and an explosion will likely result.

Methane is given off more freely when the intake stopping is erected first, because the pressure on the working faces is reduced to the extent of the water gauge producing ventilation.

In case of a fire in the center of a panel of chambers, and the return stopping is erected first, the gases generated by the fire will expand in all directions, forming a zone free from explosive gases about the fire, and any fire-damp that may be inside the fire will be held in check by reason of the expansion of the heated gases produced by the fire. While cases requiring a reversal of this method are rare, care should nevertheless be taken, and all conditions that might affect the safety of those engaged in the work should be thoroughly considered before outlining a definite plan.

In gaseous mines the temporary stoppings should not be erected gradually, as by this method the ventilating current is slowly reduced and fire-damp may accumulate and move to the fire. It is best that doors be hung so that they will close by their own weight; in this way a complete stoppage of the air current can be accomplished suddenly.

124. Effect Produced by Sealing a Mine Fire.—Air consists by volume of 20.93 per cent of oxygen and 79.04 per cent, chiefly of nitrogen, and .03 per cent of carbon dioxide. After a fire is sealed it will burn brightly until it has consumed about 3 to 4 per cent of the oxygen, after which the flame diminishes and finally dies away when the percentage of oxygen has fallen to about 13 per cent; then a smoldering fire exists.

In an anthracite mine of Pennsylvania a large fire was sealed. The territory enclosed by the stoppings contained about 3,000,000 cu.ft. of space; the fire was

affects the breathing of most people. Men may work, however, for some time in such an atmosphere, but their efficiency is considerably reduced.

The breathing of air deficient in oxygen produces the same effect as exertion.

The oxygen content is scarcely ever normal in a coal mine, owing to the gas being absorbed by the coal; this reaction between the oxygen of the air and the coal is the principal cause of the depletion of oxygen in coal mines.

When the oxygen content of the air falls below about 14 per cent an explosive mixture of methane and air becomes non-explosive.

The specific gravity of black damp varies considerably in certain mixtures. Whether or not the gas is found nearest the bottom will depend on the amount of methane present, together with temperatures and local conditions. A sample collected by the writer close to the roof of a mine contained 10.7 per cent carbon dioxide, directly below this point at the bottom the carbon dioxide content was 1.47 per cent. The oil-fed flame was extinguished in the former, but burned freely in the latter mixture.

INDEX

ook may be kept